Modeling of reservoir operations and water allocation:
New York City Delaware River Basin Reservoirs

A Thesis

Submitted to the Faculty

of

Drexel University

by

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in partial fulfillment of the

requirements for the degree

of

Master of Science in Environmental Engineering

June 2017

Drexel
UNIVERSITY

Dedications

I would like to dedicate this thesis to my family and friends, who loved, supported, and motivated to me during this journey.

Acknowledgements

I would like to acknowledge and express very special thanks my advisors Mira Olson and Patrick Gurian at Drexel University for their guidance, support, advice and patience during this study.

I also would like to acknowledge and thank the Republic of Turkey Ministry of National Education for providing the scholarship, which allowed me the opportunity to fulfill my dreams of studying in the United States.

I am also grateful to my friends, Achira Amur and Suna Ekin Sahin, for their support during this project.

Finally, I would like to express my love and deep gratitude to my family for their patience, encouragement, and unwavering faith in me. They have given me the values and education that led me to where I am today, and for that, I'll be forever indebted to them.

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Abstract

Modeling of Reservoir Operations and Water Allocation: New York City Delaware River Basin Reservoirs
Burcu Tezcan

The New York City (NYC) reservoirs in the Delaware River Basin are an essential source for goods and services, such as drinking water supply to the cities, recreation, transportation, power generation, and a host of ecosystem services. The reservoirs are located at the headwaters of the Delaware River, which supplies water to New York, New Jersey and Pennsylvania, as well as the world's largest freshwater port. However, the river is vulnerable to water shortages under changing climate conditions and needs to be managed wisely. This study developed a hydrologic model within the Stella modeling software for the NYC reservoirs to determine how historical reservoir management policies perform at meeting water demands in the basin and out-of-basin. Moreover, the model helps to better understand the interconnected effects of the water use sectors under different climate conditions and to address water shortages and water quality problems under water-stressed conditions. The model predicts reservoir releases based on inflows to reservoirs, water demand by sector and historical reservoir management policies. The model predictions are compared with historical data to assure that the model is operating in the designed manner. The impact of this study extends directly to decision makers, and stakeholders who rely on water resources in the basin. Moreover, running simulation over

the period of fifteen years record and analyzing the main droughts in the basin shows how the different operations manage drought over the historical record. These simulations will help for comparing the various operations for future scenarios.

1. INTRODUCTION

New York City Delaware River Basin reservoirs are located at the headwaters of the Delaware River Basin (Figure 1). This region is called as the Catskill Mountain Region and it provides a high quality of water to New York City (NYC) from these reservoirs; Cannonsville, Pepacton and Neversink Reservoirs. The priority of the reservoirs is water supply to the city. The reservoirs also are an essential source for goods and services for the Delaware River Basin, and thus they release water for the downstream requirements, and protect the environment along with wildlife.

Changes in climate along with population growth and economic development have important effects on water resources, especially to the Catskill region because the reservoirs in the Delaware River Basin supply approximately half of the city's municipal water supply (flood analysis). In addition, the flow in the Delaware affects the position of a fresh water and salt-water interface in the lower basin. Low flow in the river during summer and drought conditions can result in the migration of salt fronts to the upstream and thereby affects fresh water intakes used for water supply for Philadelphia and Mid-Hudson areas (Burns et. al., 2017). Furthermore, flow alterations are threatening the survival of freshwater animals, such as mussels, amphibians and crayfish. Therefore, under changing conditions, it is important to better understand effects of watershed characteristics, streamflow, climate and water demand on water resources to implement an integrated and adaptive framework for more sustainable and effective water management.

The Delaware River Basin offers a policy management model that it is for federal- state collaboration on integrated regional water management. It also addresses in-basin management while accommodating heavily out-of-basin diversions. Coordination among basins' federal-state members and with key partners helps to resolve the conflicts in the basin thanks to a unified commission. Furthermore, consideration of multiple purposes, such as water allocation in the basin, environmental requirements, flood and drought management, is allowed in the basin. Also, the management of the Delaware River Basin adheres to the doctrine of riparian rights (IWR, 2015).

The Delaware River Basin Commission (DRBC) was formed to address the major water resources problems, which require regional solutions. Due to a lack of coordination and cooperation among state, interstate, and federal agencies before the commission, the basin was experienced water supply shortages, poor water quality, and disputes over the allocation of water among stakeholders in the basin. The DRBC have helped to reduce these problems by considering the basin without borders, and jointly address the region's watershed issues in an integrated, non-duplicative, and adaptive manner. Commission programs are water supply allocation, regulatory review, drought management, water quality protection, watershed planning, water conservation initiatives, and recreation. Furthermore, the DRBC is the first federal-interstate river basin commission in the U.S. It is the first time that the federal government and a group of states joined as equal for a river basin management planning (IWR, 2015).

1.1. SCOPE OF THESIS

The Delaware River Basin Rivers are essential sources for goods and services such as drinking water, irrigation, transportation, power sector, drainage, food, recreation, and ecosystem services. These function and services are physically and economically linked with land, water and human system which evolves over time in response to changes in climate, population, and land use in the basin. Sustainable and physical bounds of use can be identified for a multi-function river basin by developing a system-oriented approach to evaluate demands of the various water use sectors in the river, and their interactions. Hence, a hydrological model is developed within the STELLA modeling software to determine how historical reservoir management policies perform at meeting water demands in the basin and out-of-basin. The model also helps to better understand the interconnected effects of the water use sectors under different climate conditions, and addresses water shortages and water quality problems under water stressed conditions.

1.2. DELAWARE RIVER BASIN OVERVIEW

The Delaware River Basin (DRB) comprises an area of nearly 13,600 square miles located in New York, New Jersey, Pennsylvania, and Delaware. Most of the basin is forested and contains important ecological lands and water bodies that are essential for people and nature. The mainstream of the river begins at Hancock, NY, and flows 330 miles to the mouth of the Delaware River Bay where it enters to the Atlantic Ocean (TNC, 2011). The DRB drains 13,539 square miles, including parts of Pennsylvania (51%), New York (18%), New Jersey (23%), and Delaware (18%) (IWR, 2015). A map of the Delaware River Basin watersheds (divided into upper, central, lower, and bay regions) is shown in Figure 1.

Based on the most recent State of the Basin Report in 2013, 15% of the basin is developed land, 49% of it is forest land, 26% of it is for agricultural use, and 10% of it consists of wetlands and water. While developed, agricultural, and wetland land cover is concentrated in the lower and bay regions, the upper and central basins have higher percentages of forestland cover.

Approximately five percent of the nation's population (over 15 million people including New York City and northern New Jersey) depends on the DRB resources. However, the basin is small, draining only 0.4% of the land area of the total continental United States. Although it is the longest un-dammed river east of the Mississippi, the tributary reservoirs total permanent storage capacity is over 400 billion gallons. Therefore, reservoir releases affect the flow in the main stem of the Delaware River and the largest tributaries. Reservoir storage and releases are used for water supply, flood control, hydropower generation, water quality management, recreational fishing and boating, and support of aquatic habitat (HydroLogics, 2004).

Figure 2. shows the trends in total water withdrawals for the DRB from 1985 to 2010. Since 1980, many of the stresses for greater water use have increased. For example, the demand has grown from agriculture (irrigation), industry, electrical power generation etc. as population has increased; yet total water withdrawals in the DRB did not rise. This shows that water conservation programs, and efficient use of water had positive effects on water resources. Figure 2.a. does not include aquaculture withdrawals in 1985, and considers only water withdrawals due to the thermoelectric sector (USGS, 1985, 2005, 2010).

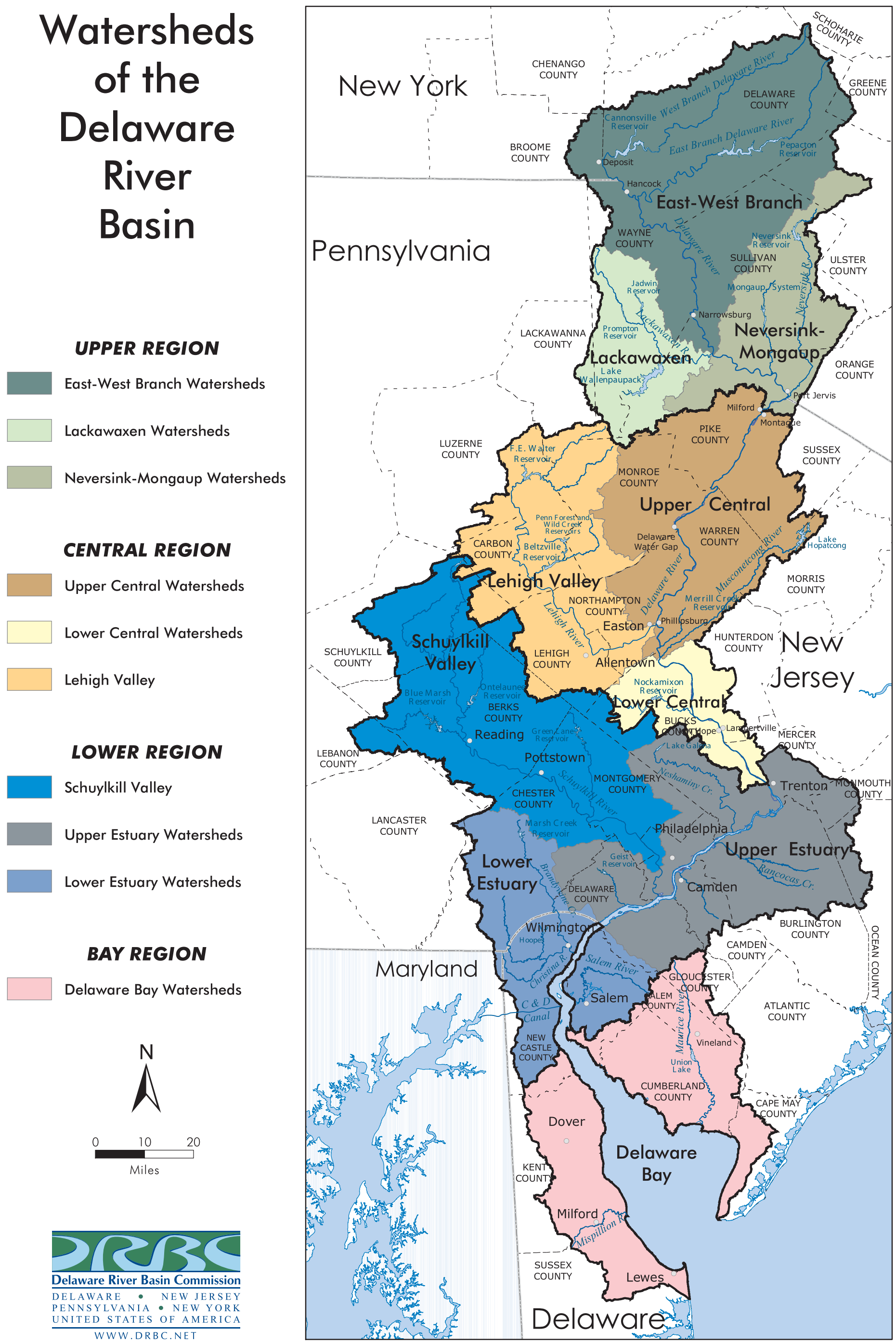
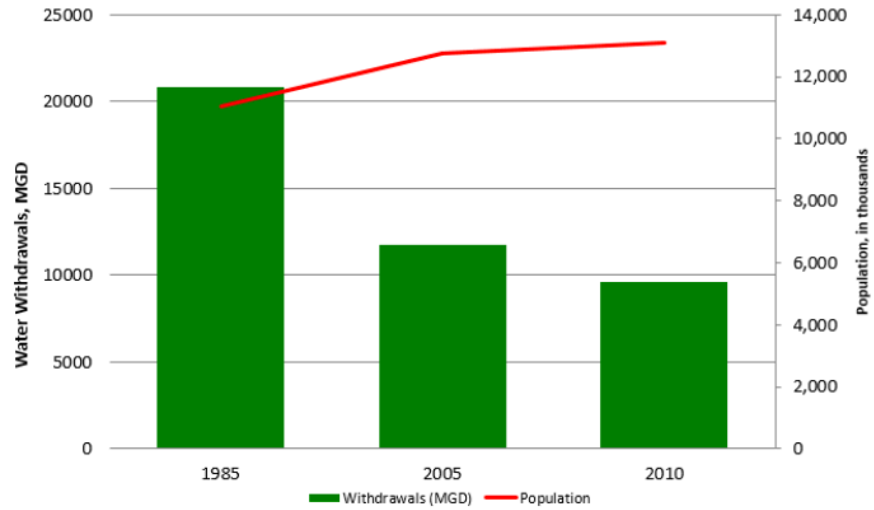
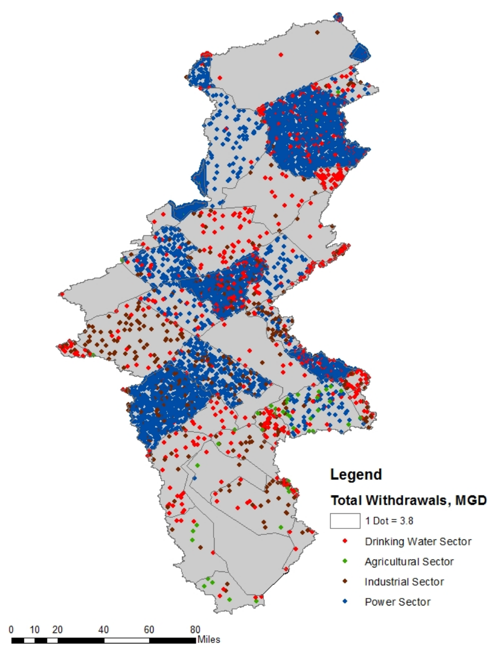


Figure 1. Delaware River Basin Map (DRBC, 2017b)



(a) 1985



(b) 2010

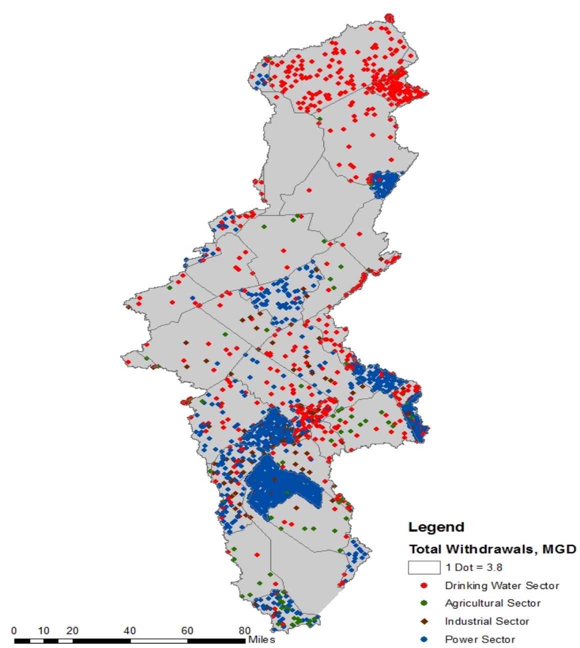


Figure 2. Trends in population and total withdrawals in (a) 1985 and (b) 2010 (USGS, 1985, 2005 and 2010)

Total withdarawals in the DRB for 2010 were divided into four major sectors: drinking water sector, including public supply and self-supplied domestic use, power generation sector, including thermoelectric power withdrawals, industrial sector, including mining and commercial water use, and agricultural sector, including irrigation, livestock, and aquacultural water use. (Figure 3).

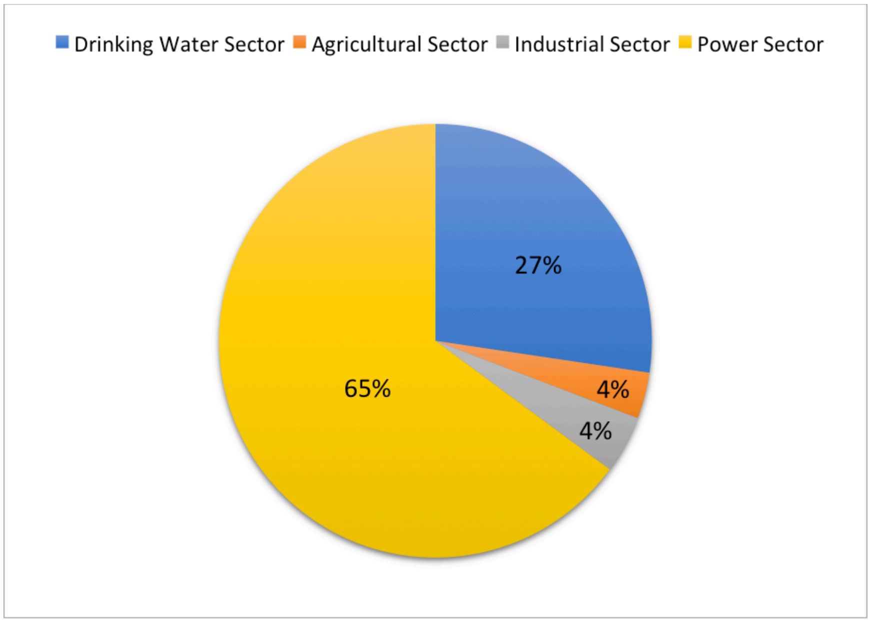


Figure 3. Sectoral Water Allocation in the Delaware River Basin for 2010

Power generation sector is further categorized into thermoelectric and hydroelectric generation power sectors. Based on a United States Geological Survey report, water withdrawals for thermoelectric power generation are considered offstream withdrawals, and therefore included in the calculation of total water withdrawal (Hutson et al., 2010). However, water used for hydroelectric power is not considered a withdrawal because water flowing through a dam is considered as an instream use (Ludlow et al., 2000).

Thermoelectric power generation is the highest water consumer in the DRB (approximately 65% of water withdrawals in 2010 and 73% in 1985), and 95% of this consumption is located in the lower basin. In 2010, the largest water withdrawals due to thermoelectric power generation were near urban centers, and were primarily on the largest rivers, such as the Delaware and the Schuylkill, and the Delaware Estuary (Hutson et al., 2010).

In 2010, instream demand for the purpose of hydroelectric generation was reported as 273 MGD for the Wallenpaupack power plant and 127 MGD for the Mongaup River System Plants (Hutson et al., 2010).

Drinking water sector is the second largest water consumer in the DRB, and represents public supply and self-supplied domestic water use categories. In 1985, approximately 18% of total water withdrawals were allocated to the drinking water sector. With population growth, water use in the basin increases, and thus the percentage of water withdrawals increased to 22% of the total water withdrawals in 2010. Sector withdrawals are mainly due to public supply water withdrawals in the upper basin for New York City and in the lower basin for the greater Philadelphia area.

1.3. WATERSHED MANAGEMENT SIMULATION TOOLS

Systems Thinking, Experimental Learning Laboratory with Animation (STELLA) by High Performance Systems, Inc., Lebanon, NH is a visual programming language for system dynamics modeling. STELLA is developed by high performance systems and was first marketed in 1986. It is an object-oriented graphical modeling environment. Groups of items in the program can simulate complex system processes. Its environment facilitates model generation, modification, and maintenance. STELLA allows the access data stored in another application program such as Microsoft EXCEL, and export data from its environment to a spreadsheet where more advanced statistical analysis can be performed.

STELLA provides a high level of user accessibility and simplifies maintenance for complex systems. It also offers the option to prevent a stock from becoming a negative. This option is important for water resources models that non-negativity option never be used (Palmer, 2010). Furthermore, the program allows the user to organize a model in conceptual unites or sectors. These unite, alternatively, can run in isolation or excluded from runs as desired by the user. This feature allows models to be highly modular.

Clarity is a very important feature in a large or complex STELLA model. In STELLA, variable names are not generic, and the user can define the names. Thereby, it permits to locate all information pertaining to a specific location without extensive searching (Palmer, 2010). STELLA also uses differential equations to describe the complex relationships in the dynamic model and to solve by Euler's method. One of the important advantages of the STELLA programming environment is in easy development of an interface for the use and navigation of the model. An appropriate interface can be developed to allow the users to communicate easily with the model (Nandalal et al, 2003).

The system dynamic simulation tool is used in this study includes specific objects that are used in representing the system structure. These specific objects are stocks, flows, converters and connecters. Stocks are used to represent variables that can accumulate. Variables whose values are measured as rates are represented as flows (Nandalal et al, 2003). Converters can be constants, variables, functions, or time series. They can be used to transform stocks and flows into other values, and represented as graphical functions. Connectors indicate the cause/effect relationships between other objects (Palmer, 2010).

1.4. WATERSHED MANAGEMENT POLICY MECHANISMS

1.4.1. History of Water Management Policies in the upper Delaware River Basin

The Delaware River Basin is of vital importance to the states of New York, New Jersey, Pennsylvania and Delaware. Its rivers have fresh and estuarine waters, which provide resources for these states as drinking water, energy generation, recreation, agriculture, fisheries and other needs. Approximately 8 million people who do not live in the basin, in New York City (NYC) and northern New Jersey, depend on the basin for drinking water purposes. The major upstream user is metropolitan New York. Three upstream reservoirs supply drinking water to NYC from the Catskill Mountains located in southeastern New York State. New Jersey is a water importer from the basin through the Delaware and Raritan Canal for the purpose of drinking water (Mandarano et al., 2013).

There have been conflicts over the management of the Delaware River for hundreds of years. One of the most important treaties was signed in 1783 between New Jersey and Pennsylvania. Based on this treaty, these two states agreed that there would be no dams on the Delaware main stem. During the 1900s, the basin states decided to focus on multiple approaches to resolve securing water allocation for growing populations. To allocate water resources equitably, New York, Pennsylvania and New Jersey appointed commissioners to negotiate a compact in 1924. However, they weren’t able to reach an agreement. Eventually NYC received a permit to export water out of the basin for the purpose of drinking water supply; The US Supreme Court decree of 1931 affirmed the diversion of 440 mgd water to NYC (Mandarano et al., 2013), and permitted the City to build two dams, Pepacton and Neversink. The location of the dams can be seen in Figure 4. However, there were no environmental interests or specified provisions for ecological flows in the 1931 decree (Ravindranath et al, 2016).

Figure 4. Delaware River Basin Reservoirs (DRBC, 2017)

After the 1931 decree, NYC and New York State petitioned the Court to increase its diversion from the Delaware River Basin for water supply purposes. Pennsylvania joined New Jersey to protest the case. An amended decree was issued on June 7, 1954 that increased NYC's diversion to 800 mgd upon the construction of the Cannonsville Reservoir located in the Delaware's West Branch. New Jersey was also allowed to allocate 100 mgd water through the Delaware and Raritan Canal. In addition to diverting water for drinking water requirements of states, the decree obligated NYC to make reservoir releases (as needed) to maintain a minimum flow requirement of 1,750 cfs at the USGS gauge station at Montague, NY or 3,400 cfs at Trenton, NJ. Furthermore, the decree required that NYC release into the Delaware River an excess release quantity (ERQ), which was estimated to be 83% of the volumetric difference between the City's total safe yield and its forecasting annual water consumption (U.S., 1954; Mandarano et al, 2013; Ravindranath et al, 2016). The safe yield was stipulated as 1,665 mgd by the Decree. A detailed explanation of the calculation of the ERQ is given in Section 2.5.3.

After recognizing that litigation through the Supreme Court is not an effective way to manage water resources in the basin, the basin states agreed on forming a commission, which negotiates a compact to guide water resources management. As a result, the Delaware River Basin Commission (DRBC) was created in 1961 and the governance of the basin unified in one body. The DRBC consists of the governors of the four states and a federal commissioner appointed by the president (Mandarano et al., 2013).

After the historical drought between 1961 and 1967, it was proved that the 1954 decree needed to be revised because it was impossible to allocate 800 mgd water to NYC from the Cannonsville, Pepacton, and Neversink reservoirs, as well as satisfy the flow requirement at Montague. In addition, it was obvious that there was a need for conservation release rules to protect downstream fisheries from low flows or excessive water temperatures. The inadequacy of conservation releases resulted in New York State's Environmental Conservation Law in 1976, which includes augmented conservation releases from the Cannonsville, Pepacton and Neversink reservoirs (experimental release program). With this law, there were also temperature targets of 75 °F as a daily maximum and 72 °F as a daily average at USGS gauges at Callicoon, Harvard, Woodbourne, and Hale Eddy located downstream of the Cannonsville, Pepacton and Neversink reservoirs. New York State Department of Environmental Conservation (NYSDEC) also specified a thermal stress bank of 6,000 cfs-day to meet these targets by cold-water releases from reservoirs. The thermal stress bank was created to ensure that enough water was actually in the reservoir for fishery protection (Ravindranath et al, 2016). The following studies by NYSDEC and experiences showed the benefit of these releases on ecosystem; as a result, docket D-77-20 CP was approved by DRBC (Mandarano et al., 2013). The combined total of the augmented releases and thermal releases could not exceed the excess release bank water quantity based on the docket D-77-20 CP. However, this rule did not take part in the first revision of the docket in 1983. After approval of the docket in 1983, instead of limiting the augmented conservation releases with the amount of water in the excess release bank, the drought operation rule curve was used to regulate the conservation releases depending on the combined storage of the reservoirs. The docket D-77-20 CP and its revisions are given in Appendix C.

In 1983, the decree parties unanimously approved Interstate Water Management Recommendations of the Parties of the Supreme Court Decree of 1954 to the Delaware

River Basin Commission Pursuant to Commission Regulation 78-20. This is generally known as the 1983 Good Faith Agreement (GFA). Under the GFA, the experimental release program, which was established in the original 1977 docket, became permanent and releases were limited based on drought operation curves, which are the main component of the GFA. Drought operation curves set a criterion that separates the levels of drought as drought warning and drought emergency based on the combined storage of the three NYC Delaware Basin Reservoirs (Figure 5).

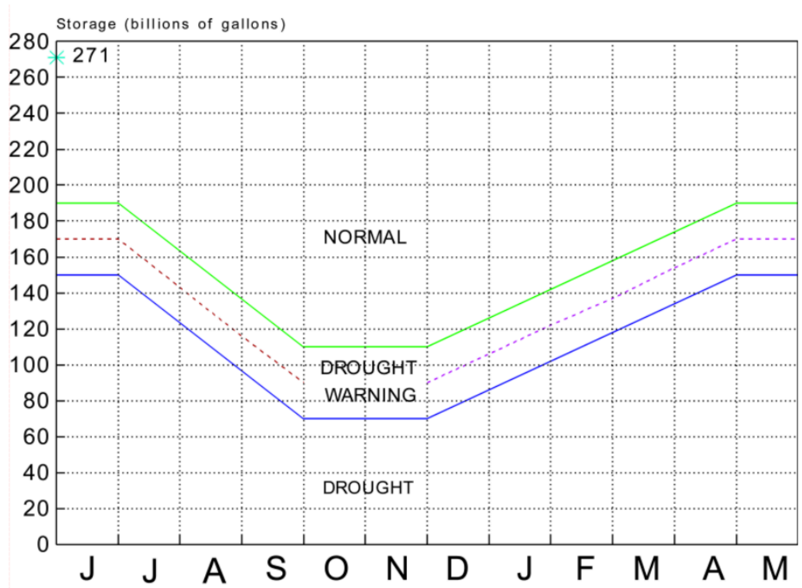


Figure 5. Drought Operation curve for Cannonsville, Pepacton and Neversink Reservoirs (DRBC, 2008)

Using these drought definitions as a framework, Table 1 shows an adaptive allocation and flow objective schedule established in the GFA. In Table 1, the drought warning line was separated into two categories which illustrated as red dashed line in Figure 5: the upper half, and the lower half. The upper half of the drought warning level were limited between the normal conditions line and drought warning line while the lower half was restricted between the drought warning and drought line. Based on combined storage of the NYC Reservoirs, the GFA sets target flows for out of basin allocations, as well as, Montague and Trenton. During drought conditions, the GFA calls for a reduction of releases out of basin, and sets a specific release schedule depending on the four predetermined salt front river mile locations for Montague and Trenton (Table 2). Drought conditions' operations are mandated by the GFA when the combined reservoir levels decrease below the drought-operating curve for 5 consecutive days (U.S., 1954; DRBC, 1982a). The GFA is given in Appendix C.

Table 1. Allocation and Flow Objective Schedule

Storage condition	NYC allocation (mgd)	NJ allocation (mgd)	Montague flow objective (cfs)	Trenton flow objective (cfs)
Normal	800	100	1750	3000
Upper half – Drought warning	680	85	1655	2700
Lower half – Drought warning	560	70	1550	2700
Drought	520	65	1100 – 1650*	2500 – 2900*
Severe Drought	To be negotiated based on conditions			

*Varies with time of year and location of salt front as shown on Table 2

Table 2. Flow Objectives for Salinity Control during Drought Periods

Seven-day Average Location of 'Salt Front' River - mile	Flow objective, Cubic Feet Per Second At:					
	Montague, N.J.			Trenton, N.J.		
	Dec - Apr	May - Aug	Sept - Nov	Dec - Apr	May - Aug	Sept - Nov
Upstream of R.M. 92.5	1600	1650	1650	2700	2900	2900
Between R.M. 87.0 and R.M. 92.5	1350	1600	1500	2700	2700	2700
Between R.M. 82.9 and R.M. 87.0	1350	1600	1500	2500	2500	2500
Downstream of R.M. 82.9	1100	1100	1100	2500	2500	2500

There were 9 revisions from the DRBC's first release policy, Docket D-77-20 CP of May 1977 until the adoption of FFMP in September 2007. Until 2007, the adjustments of conservation releases, thermal targets and thermal protection banks were minor, except the Revision 1 in November 1983, the Revision 7 in May of 2004, and the Revision 9 of September 2006 (Ravindranath et al, 2016). The revisions are explained in Section 3 and given in Appendix C.

With implementation of the GFA to the Revision 1 of 1983, there was an important modification that resulted in reduction of conservation releases to basic releases during drought warning and drought emergency conditions, and it would only be returned to the augmented levels after the combined storage reached to 25 BG above the drought warning level and remained at there for 15 consecutive days (DRBC, 2017). It is important to note that Revision 1 was the last revision approved with any expiration date. Therefore, if the decree parties cannot reach an agreement on the subsequent revisions or extensions in the future, they could fallback on the release policy defined in the Revision 1(Ravindranath et al, 2016). The Revision 1 for the Docket D-77-20 CP is given in Appendix C.

In 1999, DRBC approved Revision 4. It implemented a two-year modification to the basin wide drought management policy. It raised the drought warning line by 4 billion gallons. Also, 50 percent of the annual excess release quantity was used for enhancing the fisheries in the tailwaters below the reservoirs and made available to augment releases during drought warning. With the approval of Revision 5 in 2002, a temporary habitat bank was established to support experimental flow targets at Hale Eddy, NY, and revised minimum releases from Cannonsville. In 2002, Revision 5 was amended. Based on the amended Revision 5, using the Habitat Bank to augment flows at Hale Eddy, Harvard, and Bridgeville below the NYC reservoirs was required. Also, during drought conditions, the allowance was made to use the Habitat Bank as the summer baseline release levels to augment conservation releases. In addition, the total quantity of the thermal release bank is defined explicitly (9,200 cfs-days) in the amended Revision 5. In 2003, after the approval of the Revision 6, this amount was reduced to 4567 cfs-days (DRBC, 2017).

Revision 7 of 2004, made a number of adjustments. There were now three different banks and all of them were interrelated in a complex fashion each other. These banks were an excess release quantity bank (ERQ), a thermal release bank (TRB), and a supplemental release bank, which constituted a habitat bank. It also established a new concept by setting minimum flow targets at Hale Eddy on the West Branch of the Delaware River, at Harvard on the East Branch of the Delaware River, and at Bridgeville on the Neversink. These flow targets were subject to water availability in the habitat bank (DRBC, 2004). The conservation release rules were becoming increasingly complex with Revision 7. Consequently, The Decree Parties stated their intention to develop a long-term program. The basis of the program was considered to be based on sustainable sources of water, while releasing water based upon the overall needs in the tail waters below the reservoirs, as well as in the main stem and in the bay (Ravindranath et al, 2016). The Revision 4, 5, 6 and 7 for the Docket D-77-20 CP is given in Appendix C.

The intention for Revision 7 was to endure until May 31, 2017. However, due to severe floods in 2005 and 2006, Revision 9 was approved in 2006 resulting from political pressure of the public and the governors of New Jersey and Pennsylvania. The revision established a spill mitigation program, which aimed to increase releases from the reservoirs to achieve an 80% of reservoir void from September 1 to February 1. NYC reservoirs in the Delaware River Basin are not designed for flood mitigation; therefore the DRBC is named the program as spill mitigation rather than flood mitigation (Ravindranath et al, 2016). A detailed explanation of the revisions used in this study is made in Section 3.

The DRBC was realized the need for a sustainable long term solution to the water allocation in the Delaware River Basin due to the conflict between the New York City water supply system, ecological water demands, down basin needs, and the prominent issue of downstream flooding. As a result, in 2007, the DRBC implemented the Flexible Flow Management Program (FFMP) (Ravindranath et al, 2016)

1.4.2. Existing Water Management Policies in the Basin

1.4.2.1. Flexible Flow Management Plan in 2007

A fundamental change to the conservation release program was made with the approval of the FFMP in 2007, which established an adaptive release schedule. The drought operation curve also was revised by dividing the normal zone into two different zones: the upper L1, and the lower L2. In other words, the normal line zone in Figure 5 divided into two different levels. The remaining zones were renamed as drought watch (L3), drought warning (L4), and drought emergency (L5). Figure 6 shows the usable combined storage for the Canonsville, Pepacton and Neversink Reservoirs (Mandarano et al, 2013; USGS, 2007).

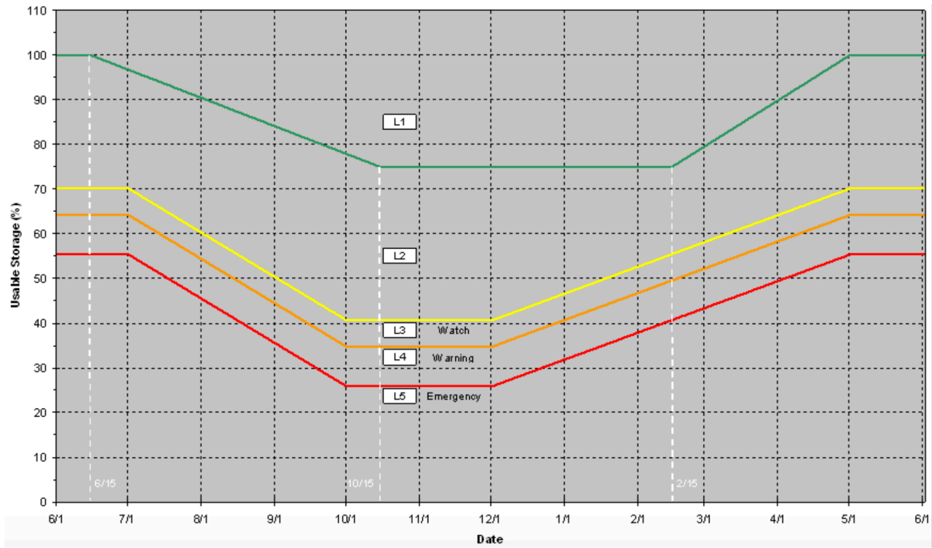


Figure 6. New York City Delaware System Usable Combined Storage (USGS, 2007)

The adaptive release schedule included releases for habitat protection and the new discharge mitigation program. The discharge mitigation releases were depending on reservoir specific storage, illustrated in Figure 7, when the combined storage is in zone L1 (Mandarano et al, 2013; USGS, 2007).

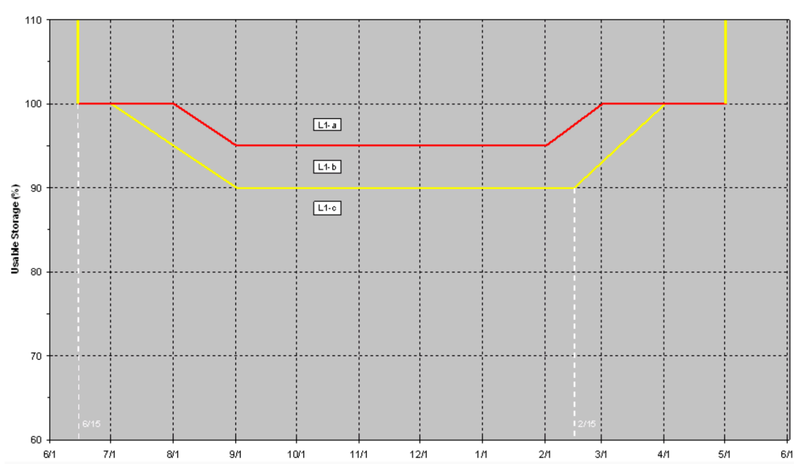


Figure 7. New York City Delaware System Usable Individual Storage (USGS, 2007).

The adaptive release schedule for each NYC reservoir was tabulated by DRBC based on four predetermined rates (0, 10 mgd, 20 mgd and 35 mgd) of forecast available flow. The forecast available flow was based on the projected unused quantity of NYC's water diversion (800 mgd). Table 3 shows the adaptive release schedule for the Cannonsville Reservoir with a projected 35 mgd available flow (Mandarano et al, 2013; USGS, 2007).

Table 3. Schedule of releases (cfs) with 35 mgd available for the Cannonsville Reservoir (USGS, 2007)

Storage Zone	Winter		Spring	Summer			Fall	
	Dec 1 –Mach 31	Apr 1 –Apr 30	May 1-May 31	Jun 1–Jun15	Jun 16-Jun30	Jul 1-Aug 31	Sep 1-Sep 30	Oct 1-Nov 30
L1-a	1500	1500	*	*	1500	1500	1500	1500
L1-b	250	*	*	*	*	350	275	250
L1-c	110	110	225	275	275	275	140	110
L2	80	80	215	260	260	260	115	80
L3	70	70	100	175	175	175	95	70
L4	55	55	75	130	130	130	55	60
L5	50	50	50	120	120	120	50	50

* Release to be made according to zone L1c

The initial implementation cycle of the FFMP was from 2007 to 2011. The FFMP was not include the parameters such as dwarf wedge mussel protection, recreational boating, Lake Wallenpaupack reservoir storage (snow melt and spill mitigation), estuary and bay ecological health, and warm water and migratory fish populations. For example, the annual reviews of the tailwaters habitat protection releases had to be submitted by New York State Department and Environmental Conservation (NYSDEC). In addition, NYSDEC must conduct a biological monitoring program in 2009 and every five years thereafter. A comprehensive reassessment study of reservoir safe yield, reservoir operations, allocations, flow objectives, and salt line were also required to conduct by the DRBC and the decree parties (Mandarano et al, 2013).

1.4.2.2. Flexible Flow Management Plan in 2011

The 2011 FFMP is a set of principles, rules and procedures for the management of storage, water supply, conservation releases, diversions, flow targets relating to the allocation of water from the Delaware River Basin (DRBC, 2011).

The FFMP was designed to provide a more natural flow regime. It was also more adaptive than the previous operating schedules for controlling releases and diversions from NYC reservoirs. The aim of the FFMP was to address competing demands in the basin, as well as drought management, flood mitigation, protection of cold-water fishery, diverse array of habitat requirements in the main stem river, estuary, and bay, and salinity repulsion (DRBC, 2011).

In 2010, NYCDEP developed the Operational Support Tool (OST) to monitor, model, and forecast the system that uses near real time data inputs. The aim of the tool was to help guide the decree parties and water system managers in managing water in NYC reservoirs and the basin. The tool was integrated into the FFMP's discharge mitigation program. The program allows the NYCDEP to predict that it can mitigate spills by targeting to achieve a conditional storage objective, a rule curve for zone L1 combined storage conditions. As a result, voids in the reservoirs can avoid from spills in case of high inflows to the reservoirs and heavy snowmelt. Table 4 shows the integrated void schedule into the FFMP (Mandarano et al, 2013).

Table 4. Void Schedule in NYC reservoirs

Time	% of void in the reservoir
July 1 – September 1	5
Sept 1 – March 15	10
March 15 – May 1	5

The current FFMP is different from the 2007 FFMP mainly in the following key elements (DRBC, 2011):

- ✓ The additional reservoir release rates tables for NYC reservoirs are added based on forecast-based available water. It does not need calculations contemporaneously for NYC's water supply.
- ✓ The OST is implemented into the FFMP to guide selection of appropriate release tables.
- ✓ Part of the releases is established based upon the recommendations given jointly by the New York State Department of Environmental Conservation and the

Pennsylvania Fish and Boat Commission Joint Fisheries Paper (January 12, 2010).

- ✓ During drought conditions, the release rates are consistent across the release tables (L3, L4 and L5).
- ✓ During drought conditions, the New Jersey diversion is modified.
- ✓ The seasonal releases design is incorporated into the FFMP
- ✓ The Interim Excess Release Quantity (IERQ) is redirected to support the seasonal flow increment
- ✓ To increase base release rates in the tables, 3.91 billion gallons of IERQ is used.
- ✓ The spill mitigation program is modified to endeavor maintaining reservoir levels at the conditional storage objective.

The latest FFMP, now called FFMP-OST, is effective until May 31, 2017. It holds the promise of further improving the ecological health of the upper Delaware River while using water more carefully.

The FFMP-OST additional releases tables, revised flow objectives, diversions to NYC and New Jersey, and combined system storage zone rules are given in Appendix D.

In this study, a STELLA model is developed to analyze the historical operations of NYC reservoirs in the upper Delaware River Basin, and water allocations with respect to water demand in the basin and out-of-basin. Twenty-four years of historical policy decisions are implemented into the model to predict reservoir releases based on inflows to the reservoirs and sectoral water use (e.g. water supply to NYC, habitat protection etc.). The purpose of developing the STELLA model for NYC reservoirs operation is to better understand cumulative effects of water withdrawals on water resources and reservoir operations under different climatic conditions. The impact of this study extends directly to decision makers in the basin, and stakeholders who rely on water resources in the basin. This study will assist environmental managers and regulators to manage strategically water resources in the Delaware River Basin under potential development and water stress conditions.

2. HYDROLOGIC MODELING

2.1. Description of the Model

A STELLA model for NYC reservoirs is developed to determine how historical reservoir management policies perform meeting water demands in the basin and out-of-basin. In addition, cumulative effects of the water users on water resources and reservoir operations were assessed to address water shortages and water quality under water stress conditions.

The model simulates twenty-four years of historical policy decisions of the NYC Delaware River Basin Reservoir System which consists of three large reservoirs; Cannonsville, Pepacton and Neversink. The main portion of the model consists of mapped water balance, which shows the inflows and withdrawals of the system (Figure 8). The inflow of the each reservoir involves historical rainfall, which fell on the surface water, and streamflows that flow into the reservoirs. The outflows of the reservoirs are the NYC water diversion, controlled releases and spill. To maintain proper operating conditions in the NYC reservoir system, water for NYC demand is transferred from the reservoirs through the diversion tunnels. In the model, water diversions were set up before the reservoir outlets. The outlets, from reservoirs to the Delaware River (From Cannosville to Delaware, From Pepacton to Delaware, From Neversink to Delaware), consist of the controlled releases and spill. The spill is activated based on the reservoir operation zone. The spillway simply dumps the excess water when reservoir volume is above the operation zone. The Cannonsville and Pepacton reservoir releases meet at the Delaware River above Port Jervis. Then, they join with releases from the Neversink Reservoir at Port Jervis.

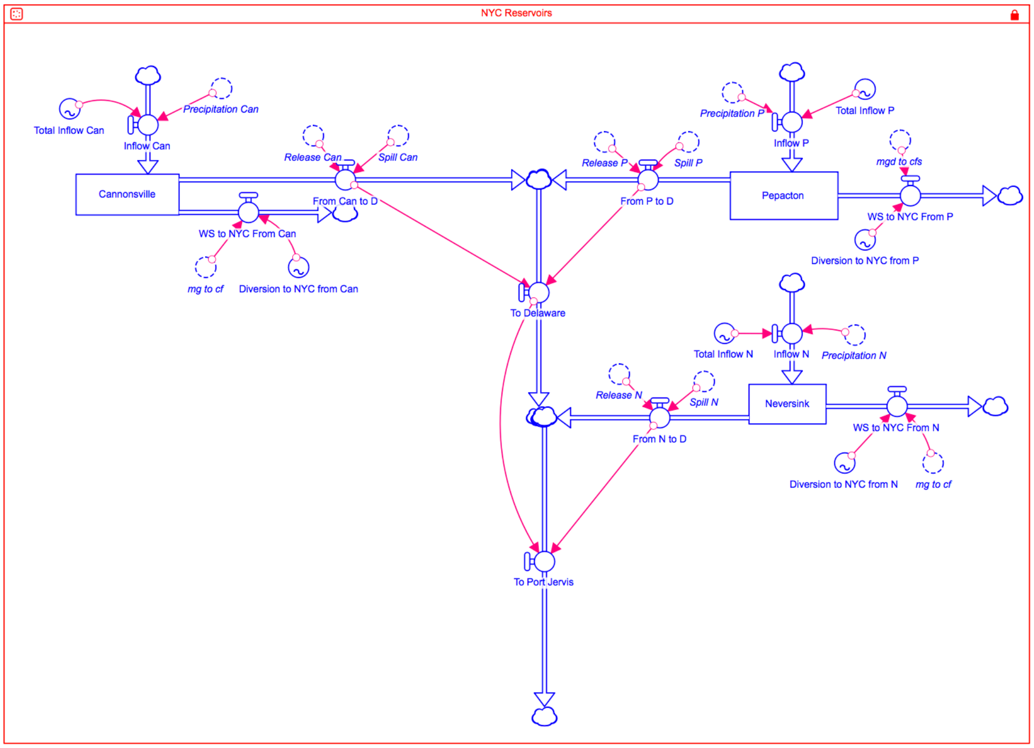


Figure 8. The STELLA model of the NYC reservoirs in the Delaware River Basin

The controlled releases from the reservoirs are based on total water demand of the basin. The daily water demand for each sector is determined and added into the demand equation for each reservoir. Figure 9 represents total water demand that needs to be released from the Neversink Reservoir. The pink, purple and blue dashed nodes represent the conservation releases, direct releases to meet the Montague flow target, and thermal releases from the Neversink Reservoir, respectively. The controlled releases are made to meet water demand of the basin if the volume of the reservoir is above the total volume of the demand. In this case, the total amount of the demand is released from the reservoirs. If it is not above, the total volume of the reservoir and the inflow are released. The controlled release sector is illustrated in Figure 10. The dashed square represents the

Neversink Reservoir while dashed nodes symbolize the inflow and the demand that needs to be released from the Neversink Reservoir to maintain the basin requirement.

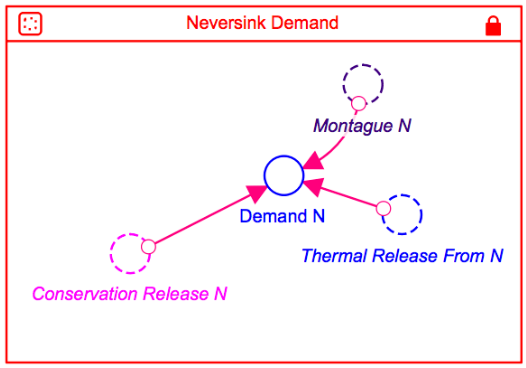


Figure 9. Water Demand Sector for the Neversink Reservoir

The basin demands are categorized into three different water use sectors for each reservoir: Wildlife and aesthetic use (conservation releases), fishery protection (thermal releases) and lower basin water demand (direct releases for the Montague flow target).

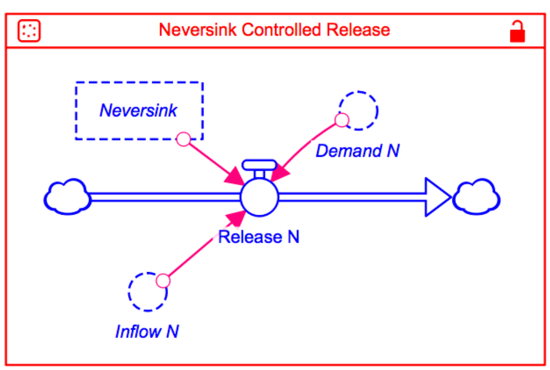


Figure 10. Controlled Releases from the Neversink Reservoir

The NYC model uses a daily time step. It runs for 15 years of record (1980 – 1995) to simulate the reservoir releases from the outlet of each reservoir. The reason why the model runs until 1995 is because of the data availability for the Rio Reservoir. The reservoir release data, which are used to calculate the uncontrolled streamflow above Montague are available until 1995. The model outputs are compared with historical data to assure that the model is operating in the designed manner. The results are shown in Section 4.

There are different types of banks in the NYC STELLA model. The aim of these banks is to store water into the reservoirs for water demands of various sectors in the basin. Excess release bank store water to maintain the Montague flow target. However, in case of emergency, the DRBC might use water from excess release bank for thermal releases or lower basin water demand. Thermal release bank is used to support fishery habitat in the downstream of the reservoirs, and habitat bank is established to support tailwaters downstream of the reservoirs. The DRBC assigns a certain amount of water to these banks for every year, and the releases based on the basin demand are limited with these banks. In case of drought emergency conditions, the DRBC might establish additional amount of water to use for downstream purposes. The banks are their priorities are given in Table 5. No releases are made if excess release bank equals to seasonal quantity for lower basin demand, or if thermal release bank equals to the amount of water that the DRBC established for the fishery protection, or if habitat bank equals to the amount of water that the DRBC established to support tailwaters of reservoirs. The habitat bank is established by the DRBC in 2002.

Table 5. The banks in the basin and their priorities

Basin Bank	Priority
Excess Release Bank	Lower Basin Demand
Thermal Release Bank	Fishery Protection
Habitat Bank	Tailwaters Habitat Protection

The overview of the model inputs and outputs, and how they connect with each other for the NYC reservoir system are given in Figure 11. Also, a general overview of operation for modeling of the basin demand is illustrated in Figure 12. The detailed calculations and historical policies are given in Section 2, and Section 3, respectively.

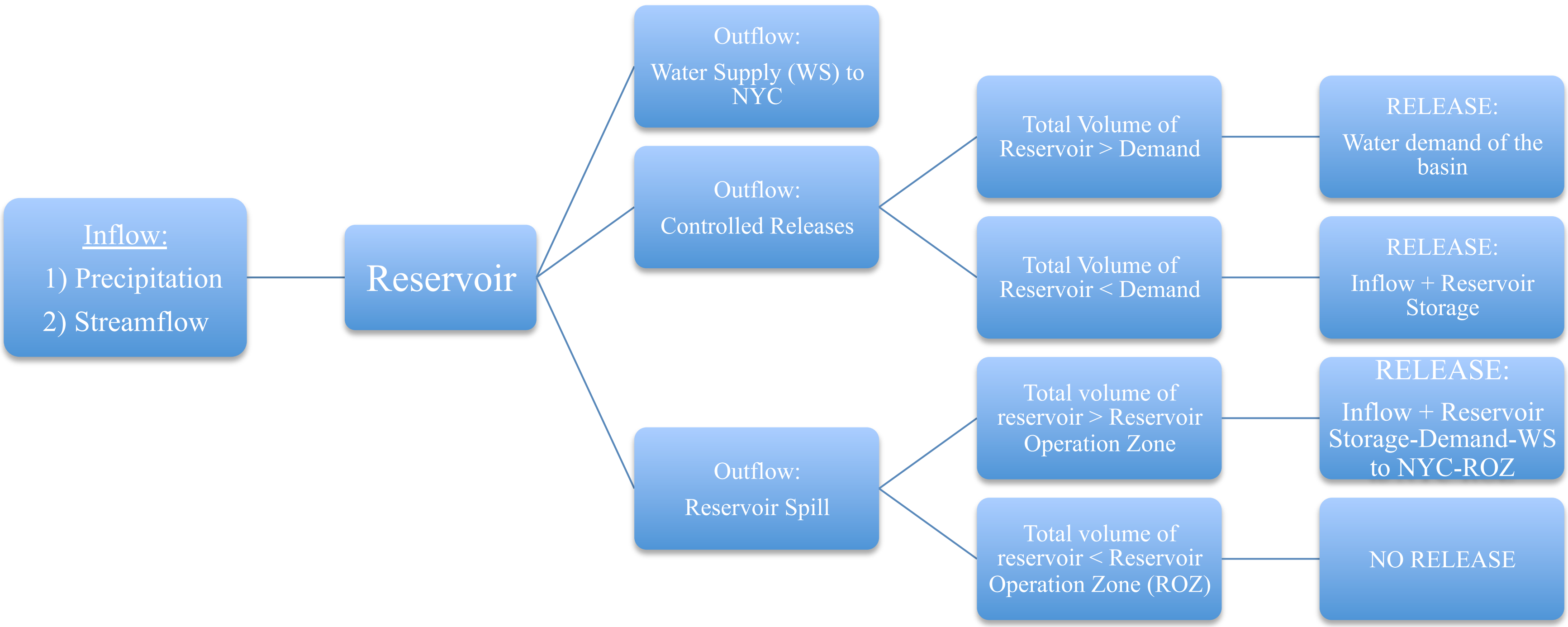


Figure 11. The overview of the reservoir inputs and outputs

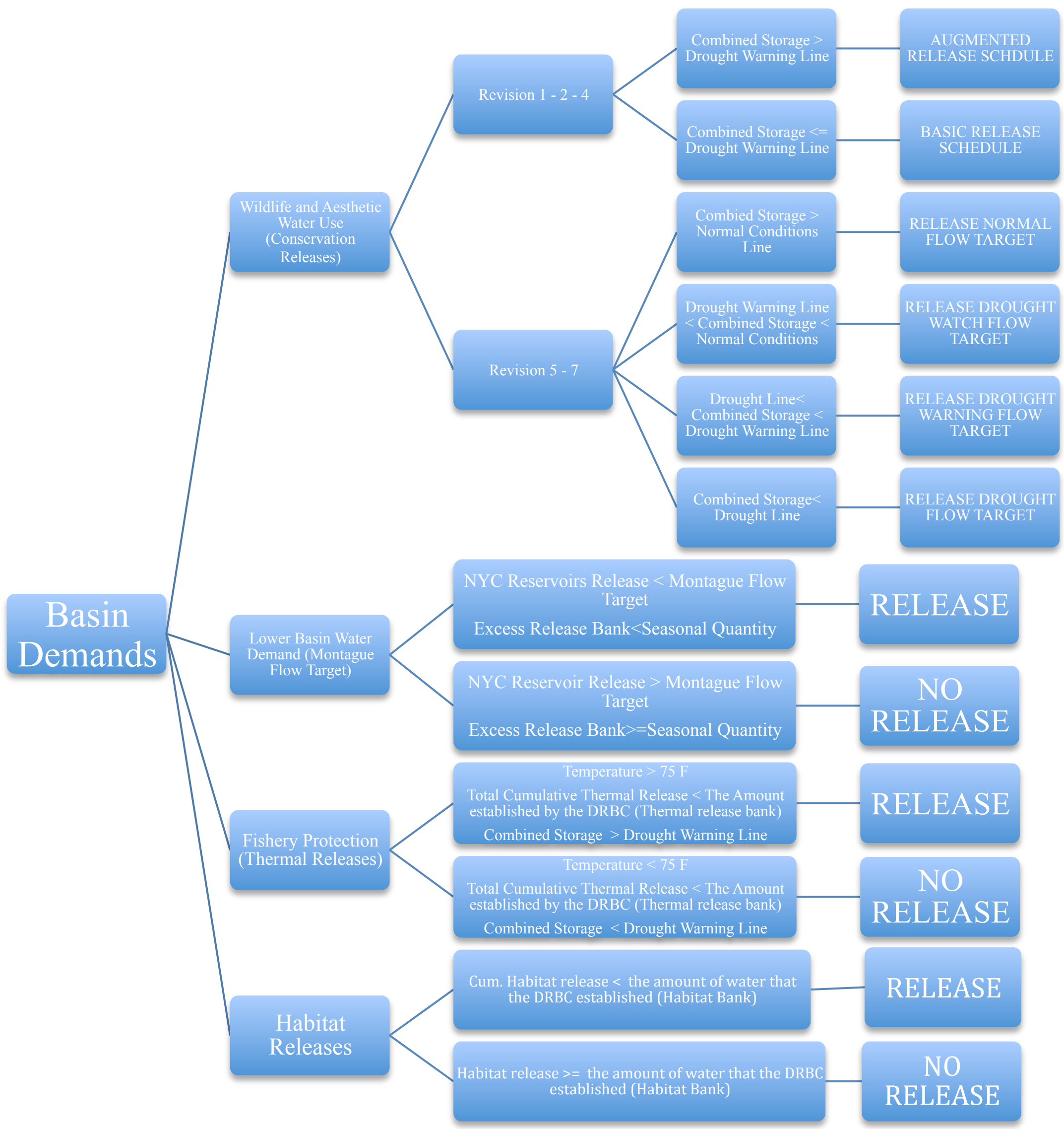


Figure 12. The overview of the Operation of the Basin Demand

STELLA allows the user to categorize a model in conceptual units or sectors. A unit is a group of elements that contributes a major process , such as release from a reservoir (Figure 10), or inflow to a reservoir. The NYC model contains numerous units. In the model all units can be run simultaneously. Alternatively, each unit can be run individually. The major process for the NYC STELLA model is shown in Figure 8.

In the model, some of the units contain elements that interact to simulate the operations and components of the system. Figure 13 shows an example of the conservation release unit for the Pepacton Reservoir used in the model. The green dashed nodes represents the revisions made by the DRBC during twenty-four years. Based on the each revision, the release schedules were changed. The other units are responsible for generating output results, such as spill and demand units. Therefore, the NYC model is a very complex and comprehensive simulation model. It can be run either completely or focusing on individual units.

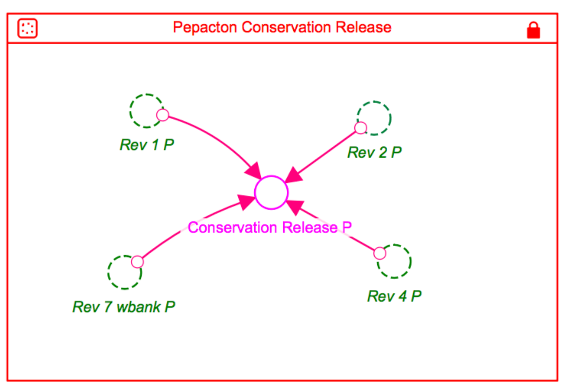


Figure 13. Conservation release unit for the Pepacton Reservoir

2.2. Quantification of Inflows

The primary inflows to NYC reservoirs in the Delaware River Basin are influent streamflow and direct precipitation. Streamflow data comes from two different sources. Some of the data are actual data as measured by the USGS at gauging stations. The remaining ungauged inlets are estimated using the StreamStats online software program and the Delaware River Basin Streamflow Estimator Tool (DRB-SET) established by the USGS. The basin characteristics are identified for ungauged stream locations in the StreamStats Beta Version 4. Then, daily mean streamflows are computed in the DRB-SET for selected locations in the Delaware River Basin. Also, direct precipitation onto the NYC reservoirs is considered in the model. The following is a breakdown of the inputs into the NYC reservoirs.

2.2.1. Gauged flows

The West Branch of the Delaware River is the larger stream that flows into Cannonsville Reservoir. USGS has a stream gage station at Walton, NY (01423000). The other major stream that flows into Cannonsville Reservoir has a USGS stream gage station on it, Trout Creek (0142400103). The drainage area of Walton and Trout Creek is 332 and 20.2 square miles, respectively.

The streams that flow into Pepacton have four USGS gaging stations located on them. One of the larger streams, which flows into Pepacton Reservoir, is located at the East Branch of the Delaware River. There is a USGS stream gage station on it, Margarateville (01413500) with the drainage area of 163 square miles. The other USGS stream gages are located at Platte Kill (01414000), Tremper Kill (1415000), and Mill Brook (01414500). The drainage area of these stations is 35, 33, and 25 square miles, respectively.

Neversink River, which flows into Neversink Reservoir has only one USGS gaging station on it; Claryville (01435000). The drainage area for the station is 66 square miles.

2.2.2. Ungauged flows

Most of the streamflows that feed the NYC reservoirs are ungauged. To estimate the daily mean flow into the reservoirs, after basin delineation in the StreamStats Beta Version 4, the basin characteristics for the selected location are automatically entered into the DRB-SET tool. The tool uses map correlation to select an appropriate reference gage in order to calculate daily mean streamflow based on the basin characteristics. It uses the closest streamgage to the ungauged stream location. The daily mean streamflow data taken from the tool is between 1960 and 2010. Table 6 shows the name of each ungauged stream used in the model, and its drainage area for all NYC reservoirs.

Table 6. Ungauged Streamflows and their drainage area for the NYC reservoirs

Cannonsville		Pepacton		Neversink	
Stream Name	Drainage Area (mi^2)	Stream Name	Drainage Area (mi^2)	Stream Name	Drainage Area (mi^2)
Dry Brook & Barbour Brook	4.42	Bush Kill	6.08	Black Joe Brook	1.75
Loomis Brook	12.50	Close Horrow	1.54	Conklin Brook	3.02
Sherruck Brook	5.48	Dingle Hill	1.78	Hollow Brook	1.22
Johnny Brook	3.28	Perch Lake Stream	1.16	Dry Brook	0.76
Dryden Brook	9.44	Barkaboom	7.29	Aden Brook	2.79
Chase Brook	4.75	Shaver Hollow	2.73		
		Beeech Hill Brook	6.92		
		Flynn Brook	0.7		
		Holiday Brook	4.73		
		Murphy Hill	1.73		
		Bryden Hill	15.10		
		Fall Clove	11.20		
		Huntley Hollow	2.13		
		Cat Hollow	4.01		

2.2.3. Direct Precipitation

To calculate the volume of direct precipitation ($V_{P\text{-direct}}$) into the NYC reservoirs, local precipitation (P) for each reservoir is multiplied by the reservoir surface area (A) at the spillway crest elevation. As a result, the volume of water that falls directly into the reservoir is calculated (Equation (1)). Twenty-four years of daily precipitation data for each reservoir was taken from the CLIMOD2 online tool established by the Northeast Regional Climate Center. Table 7 shows the surface area of each reservoir and location of the stations.

$$V_{P-direct} = P * A \tag{1}$$

Table 7. Surface area of each reservoir and location of precipitation gages for the NYC reservoirs (NYCDEP,1974)

Reservoir Name	Surface area (acre-feet)	Precipitation gage
Cannonsville	293,530	Walton, NY
Pepacton	429,660	Walton, NY
Neversink	107,170	Rock Hill 3 SW, NY

2.3. Reservoir Mass Balance

The basic concept of a mass balance is change in storage, which equals to sum of the inflows minus sum of the outflows as illustrated in Equation (2).

Change in storage $=[\sum \text{inflows}] - [\sum \text{outflows}]$ (2)

Looking in detail at the mass balance for the NYC reservoirs, Equation (3) incorporates all the components into the hydrological system of the reservoir.

Change in storage = Initial storage of the reservoir + (precipitation that fells onto the reservoir + streamflow that run into the reservoir) – (spill + controlled release + Water Supply to the NYC from the reservoir) (3)

2.4. Quantification of Outflows

The outflow of the system is regulated by release and seasonal reservoir spills. The release for each reservoir includes daily water demands for different sector groups: Conservation releases for wildlife and aesthetics, thermal releases for fishery protections, and direct releases to maintain the Montague flow target for lower basin water requirement.

The NYC water demand is diverted from the reservoirs before the outflow via diversion tunnels. In the model, the diversion of water from these reservoirs is represented with a diverted outlet from each reservoir. The three diverted outlets, Water Supply to NYC from Cannosville, Water Supply to NYC from Pepacton, Water Supply to NYC from Neversink, are drawn as flows in the schematic shown in Figure 19 The following is a breakdown of the outputs from the NYC reservoirs.

2.4.1. Demand

There are three kinds of water use sectors in the NYC model defined in Section 2.5.2. Releases are made depending on the water demands of these sectors. As well as, the habitat bank releases are implemented into demand after 2002. Equation (4) defines the total demand for water use sectors in the basin. The first part of the equation is limited until 1983 due to commitment defined in the Docket D-77-20 CP. Based on the commitment, the augmented conservation releases and the thermal stress releases cannot exceed the total volume of the excess release bank during any water year. Therefore, the cumulative volume of the thermal releases and the augmented conservation releases were limited to the cumulative volume of the excess release bank, and the conservation releases is defined in first part of the demand equation together with the thermal releases. The Docket D-77-20 CP is given in Appendix C.

Demand = IF TIME >= 0 AND TIME <= 1126 THEN Thermal & Conservation Releases + Direct Releases for Montague ELSE IF TIME > 1126 AND TIME < 7788 THEN Conservation Releases + Thermal Releases + Direct Releases for Montague ELSE Conservation Releases + Thermal Releases + Direct Releases for Montague + Habitat Bank Release (4)

2.4.2. Controlled Reservoir Releases

The amount of controlled releases from NYC reservoirs is based on the total volume of inflow and storage of the reservoirs. Equation (5) indicates that if the volume of water in the reservoir and the inflow is sufficient to meet the demand, then the demand is released. If it is not, the amount of water from reservoir's storage and the inflow are released.

Release = IF Inflow + Reservoir Storage >= Demand THEN Demand ELSE Inflow + Reservoir Storage (5)

2.4.3. Reservoirs Spillway

When the volume of the each reservoir exceeds its seasonal pool operation zone, the excess water is released over the spillway. The seasonal pool operation zone is the long-term median storage of reservoir given in Section 2.5.1. Equation (6) states that if the total volume of the reservoir and inflow minus the demand and the city water diversion are greater than the volume of the reservoir operation zone for the each reservoir, then spill is to be calculated. If it is not, the spill equation is set equal to zero. In other words, the spill is activated based on the reservoir operation zone, and dumps the excess water if reservoir volume is above the operation zone. Also, the outflow of the reservoirs consists of the controlled releases and spill.

Spill = IF Inflow + Reservoir Storage - Demand –Water Supply to NYC From Reservoir >= Seasonal Reservoir Pool Operation Zone THEN Inflow + Reservoir Storage – Demand – Seasonal Reservoir Pool Operation Zone –Water Supply to NYC From Reservoir ELSE 0 (6)

2.4.4. Diversion to NYC

The diversion of water to NYC is independently modeled from the demand equation due to the location of the diversion tunnels in the reservoirs. Water demand for NYC is taken directly from each reservoir via tunnels before the reservoirs discharge. Therefore, the three diverted outlets, Water Supply to NYC from Cannosville, Water Supply to NYC from Pepacton, Water Supply to NYC from Neversink, are directly taken out from each reservoirs in the model (Figure 19). A detailed explanation of the diversions to NYC is given in the Section 3.2.6.

2.5. Modeling of the Operation of the NYC Reservoir System

2.5.1. Seasonal Reservoir Pool Operation Zone

Each reservoir has been modeled based on a seasonal reservoir operation zone, which is a function of time and volume of the reservoir. The reservoir operation zone is implemented into the model to regulate spill from the reservoirs depending on the volume of water inside the reservoir. Long-term median storage is computed on the basis of 23 years of reservoir volume records to calculate the daily seasonal reservoir operation zones. Based on the operation zone, when the total volume of reservoir and inflow is higher than the volume of the pool zone at the specific time steps, the reservoir spills. Figure 14, 15, and 16 show the volume of the seasonal pool operation zones depending on the time for each reservoir. The daily reservoir storage data is taken from Delaware River Master Report for the period of between 1980 and 2005 (ODRM, 2016).

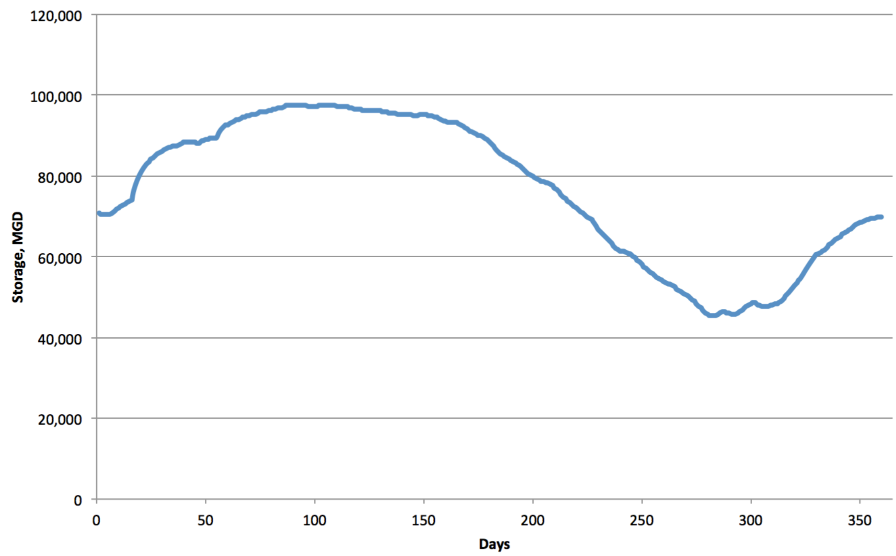


Figure 14. Seasonal Pool Operation Zone for Cannonsville Reservoir

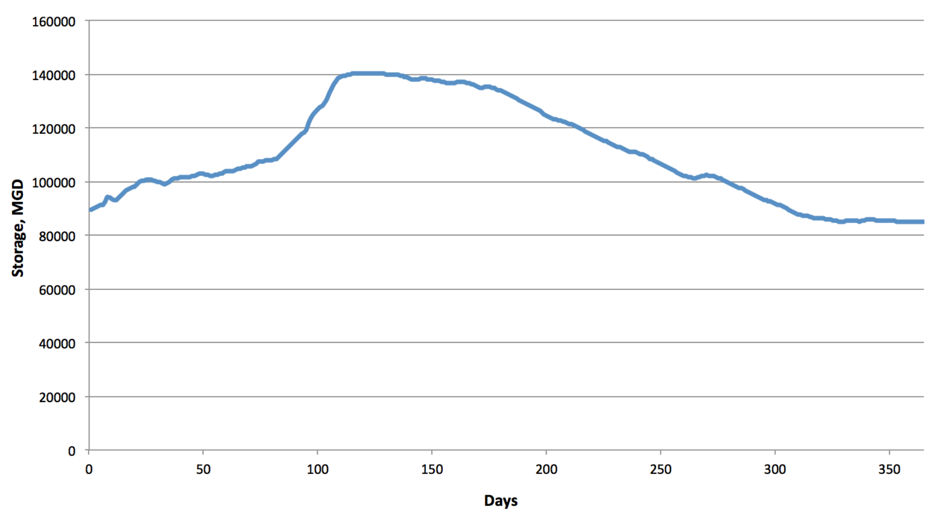


Figure 15. Seasonal Pool Operation Zone for Pepacton Reservoir

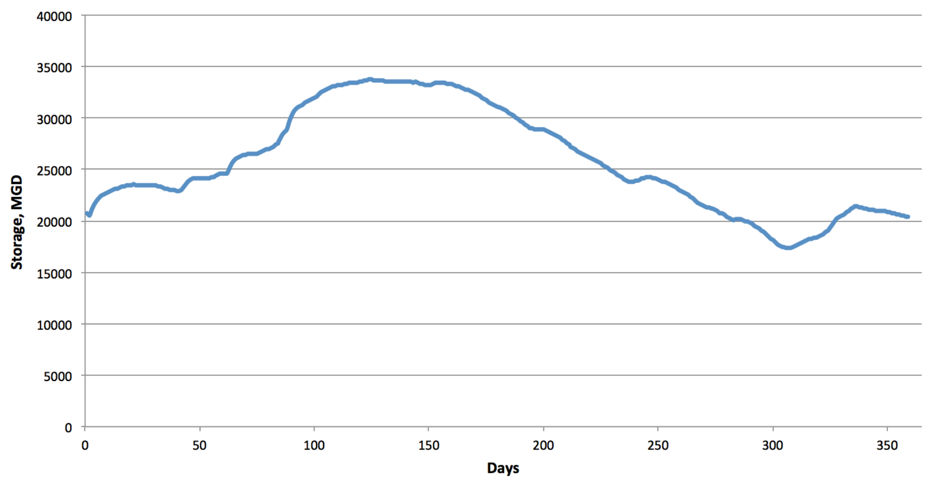


Figure 16. Seasonal Pool Operation Zone for Neversink Reservoir

The reservoirs pools used in the modeling are delineating according to operational zone for each reservoir. In addition to drought operation curves, the model needs a seasonal operation zone to represent an amount of seasonal storage in the reservoirs, which regulates the spill from the reservoirs. This approach has its strengths and weaknesses. For example, the seasonal pool operation zones include historic deviations from target level. Therefore it might underestimate the target storage in the reservoir, and thereby overestimate the reservoir releases during period of water abundance. However, this approach is applicable under normal and water stress conditions since the target demands are defined in the process.

2.5.2. Modeling of Water Demand Based on the Water Use Sector Groups

The amount of water released from the NYC reservoirs depends on the water demand of water use sector groups. The aims of these groups are divided into three categories: maintaining the conservation of wildlife and aesthetic of the environment (conservation releases), protecting fishery habitat (thermal releases), and supporting lower basin water demand (direct releases for the Montague flow target).

2.5.2.1. Wildlife and Aesthetic Water Use

Conservation release schedules had been established to protect wildlife and aesthetic of the environment at the downstream of the reservoirs. The schedules had been revised four times for the Pepacton and the Neversink Reservoirs, and five times for the Cannonsville Reservoir between 1980 and 2005. Each revision has been modeled in STELLA individually based on its schedule. If the combined storage of the NYC reservoirs is above the drought warning line, and maintains 15 billion gallons (BG) above this level for 15 consecutive days, the reservoirs release water depending on the augmented release schedule, named Normal Conditions in the model. If it is below the line and stays 5 consecutive days below or at the drought warning level, then reservoirs release water based on basic release schedule, named Drought Emergency in the model. After 1999, the drought warning line was increased 4 BG. Therefore, there are two different drought-warning lines in the model: the drought warning rev1, which runs until 1999, and the drought warning rev4, which runs after 1999. Revision 4 and the later revisions use the drought warning rev4 to regulate the conservation release schedule. As an example, a modeling of the conservation release (Revision 2) for the Pepacton Reservoir is drawn in the schematic shown in Figure 17.

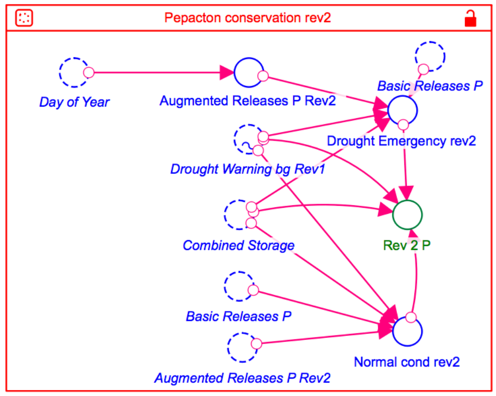


Figure 17. Modeling of the Conservation Release (Revision 2) for Pepacton Reservoir

In 1999, the upper half of the drought warning line was named as the drought watch, while lower part was named the drought warning. In 2002, the release schedule was revised based on the stages in the drought operation curve. For example, if the combined storage of the three reservoirs were below the normal conditions line, and above the drought warning line, then releases from the Pepacton Reservoir would be 30 cfs (Table 10).

With the approval of Revision 7, the reference releases are implemented into the system to regulate the conservation releases if the habitat bank is exhausted. Under this revision, the remaining habitat bank is calculated in the model, and implemented into the conservation releases equation for the Revision 7. As a result, the NYC reservoir releases are made in the model based on the reference release schedule if the habitat bank set equal to zero. Revisions for conservation releases to meet the demand of wildlife and aesthetic are depicted in Section 3.2.2. and they are given in Appendix B.

2.5.2.2. Fish Demand

To protect trout species downstream of the NYC reservoirs, thermal stress releases are made from each reservoir. Historical releases were made whenever the maximum water temperature at designed downstream USGS gaging stations, Harvard (station number: 01417500), Woodbourne (station number: 01436500) or Hale Eddy (station number: 01426500), exceeded a maximum of 75 °F. The temperature data for each station is taken from USGS. However, there is no water temperature data for the Woodbourne station. Thus, the Bridgeville station is used to get daily maximum water temperature data. The Bridgeville station is located 17 miles downstream of the Neversink Reservoir, and 11 miles downstream of the Woodbourne station.

The cumulative volume of these releases was restricted to 6,000 cfs-days from all reservoirs, and it is used between May 1st and November 1st. Furthermore, the thermal stress releases can be released if the combined storage of the NYC reservoirs is above the drought warning line. The thermal release equation for the Neversink Reservoir is illustrated in the Equation (7) However, there are some exceptions. In case of drought emergency conditions, thermal releases can be made under the drought conditions for fishery production, and additional releases can be added to 6,000 cfs from the excess release bank. The historical thermal stress release revisions, including exceptional emergency conditions, are explained in Section 3.2.4 in detail, and given in Appendix B.

Thermal Release = IF Day of Year>120 AND Day of Year<=304 AND Total Cum Thermal Rel<= 6000*86400 AND Combined Storage > Drought Warning Line AND

Temp Bridgeville >= 75 THEN Observed Neversink Release - Release for Montague from Neversink – Conservation Release N ELSE 0 (7)

The thermal release equation goes into the demand equation, and is combined with the wildlife and aesthetic water demand (or conservation) and lower basin demand. Then, the release from the reservoirs is regulated based on the release equation. The demand and release equations are explained in Section 2.4.1. and 2.4.2., respectively.

The actual /observed data is used to calculate water for fish demand because of limitations in the software. The STELLA produces a warning message of a circular connection of the simulated outflow and thermal release (or fish demand) sector. Therefore, simulated outflow cannot be used in the thermal release equation.

2.5.2.3. Lower Basin Water Demand

The Montague flow target was established in 1983 based on the drought operation curves to ensure that the lower basin gets enough water. Based on the combined storage of the NYC reservoirs, different target flows were established at Montague (Table 6). For example, if the combined storage is above the upper half of the drought warning line (named as the drought watch in 1999) and below the normal conditions line, then the target flow at Montague should be 1,655 cfs. In the model, direct releases from the NYC reservoirs are made based on the different flow targets at Montague under normal, drought warning, and drought conditions.

Flows of the Delaware River at Montague are composed of following parts:

I. Controlled releases from Lake Wallenpaupack on Wallenpaupack Creek, Pennsylvania for the production of hydroelectric power.

II. Controlled releases from Rio Reservoir on the Mongaup River, New York for the production of hydroelectric power.

III. Uncontrolled runoff above the Montague, New Jersey.

IV. Controlled releases from Cannonsville, Pepacton, and Neversink Reservoirs of the City of New York.

New York City reservoir releases are necessary to maintain the Montague flow objective. However, determination of the amount of release from each reservoir is complex because there is a time difference between the combined flows from the other sources and required flow at Montague. Table 8 shows the average times for the travel of water from different reservoirs to Montague, New Jersey (ODRM, 2016).

Table 8. Travel times of water from various reservoirs to Montague, New Jersey (ODRM, 2016).

Reservoir	Hours
Pepacton	60
Cannonsville	48
Neversink	33
Lake Wallenpaupack	16
Rio	8

Water released from the Pepacton Reservoir arrives at the USGS stream gage station at Montague in 60 hours. The Cannonsville and the Neversink Reservoirs releases also reach Montague concurrently with releases from Pepacton reservoir. To allow for differences in travel times, releases from the NYC reservoirs were scheduled. Based on the schedule, daily directed releases begin from the Pepacton reservoir after 12 hours, from the Cannonsville Reservoir after 24 hours, and from the Neversink Reservoir after 15 hours the following day. As a result, the direct releases are made from all reservoirs at the same time to maintain the Montague flow target. Similarly, releases from Lake Wallenpaupack were computed on 24-hour basis beginning at 8 hours to compensate for the travel time to Montague (ODRM, 2016). Equation (8) is set based on the travel times from reservoirs to Montague, NJ.

Based on calculations in the Delaware River Master Reports, uncontrolled runoff is computed as a residual by subtracting the controlled reservoir releases from the observed discharge at Montague. To account for the uncontrolled runoff in the model, the computation requires estimating releases from the NYC reservoirs after three days, and the power reservoirs after a day. The release data for the NYC reservoirs, and the power reservoirs (Lake Wallenpaupack and Rio) was provided through USGS records.

Equation (8) describes direct releases from the NYC reservoirs for maintaining the Montague minimum flow target requirement. Based on the equation, if the volume of uncontrolled runoff along with the volume of releases from the power reservoirs (1 day delayed), and conservation releases of each reservoir (3 days delayed) is lower than the total volume of Montague minimum flow target and excess release quantity, the reservoirs release. If it is not lower, the Montague release from each reservoir is set equal to zero. As an example, calculation of direct releases from Pepacton Reservoir to maintain the Montague flow target is depicted in Equation (8)

Montague Flow Release = IF Power reservoirs releases (t+1) + Uncontrolled Releases (t) + Conservation Releases for Pepacton (t+3) + Observed Neversink release (t+3) + Observed Cannonsville release (t+3) <= Montague Min Release + Excess Release THEN Montague Observed (t+3) – Observed Neversink Release (t+1) –Observed Cannosville Release (t+1) – Uncontrolled Releases (t+3) – Power Releases (t+3) – Conservation Release for Pepacton (t) – Thermal Release from Pepacton (t) ELSE 0 (8)

The STELLA has limitations to use simulated outflow in the Montague flow release equation due to a warning message of a circular connection of the simulated outflow and lower basin water demand (or the Montague flow release). Therefore, the observed/actual historical release data used in the Equation (8).

In the model, releases from the reservoirs are made depending on the Montague minimum flow target schedule established in GFA (Table 6 and Table 7). However, the GFA was signed by the basin states governors and the Mayor of New York in February 1983 (Weston et al., 1989). Therefore, minimum flow targets in Montague from 1981 to 1983 are considered in the model based on the Delaware River Master Report. (ODRM, 2016). Minimum required rates of flow at Montague in accordance with the design data of the River Master are presented in Appendix B.1.

Also, due to emergency conditions in the basin, the DRBC temporarily amended the release schedule at Montague in 1985. Therefore, the amended release schedule is implemented in the model for 1985, and releases are made depending on various flow targets at the specific salt line locations instead of the specific flow target established in the GFA for drought warning condition. The savings due to reduction of the Montague flow target are stored in the excess release bank. The temporarily amended schedule of the Montague target flow is explained in detail in Appendix B.2.

2.5.2.3.1. Estuary Salt Line Movement

To protect lower basin drinking water intakes from the salt-water intrusion of the ocean, NYC reservoirs release water during drought conditions. The releases are made if the 7-day average chloride concentration in the water is in excess of 250 mg/L. Therefore, a drought operation formula is created in the model depending on 7-day average chloride concentrations calculated by using daily special conductance and temperature data. If 7-day average chloride concentration at the station was greater than 250 mg/L, then releases were made based on location of the salt line to maintain the target flow at Montague under the drought storage level. The drought operation formula goes into the effect automatically whenever combined storage of NYC reservoirs declines below the drought line and remains below that level for 5 consecutive days. Reservoir releases to maintain Montague minimum flow requirement during drought conditions varied based on the location of salt line and time as illustrated in Table 2. Drought operation formula was integrated into the Montague minimum flow target equation in the model and linked with operating rule curves as defined in Figure 5. For example, if combined storage of NYC reservoirs was equal or greater than normal storage level, the releases from NYC reservoirs to maintain the minimum daily Montague target would be calculated based on the flow objective of 1750 cfs at Montague, or if it was equal or lower than drought storage level, then the NYC reservoirs releases will be linked to salt line locations, and calculated based on the flow objectives defined in the drought operation formula.

Chloride concentration was not directly measured at the monitoring sites. Instead, a mathematical relationship between conductance, temperature and chloride concentration has been developed by Pollak (1954) and modified by Pritchard (1978). Based on this algorithm (Equation (9) and Equation (10)), daily chloride concentration is calculated (Miller et al, 1988). The conductance and temperature data were collected from the Delaware River by four water quality monitors located at Reedy Island, Delaware (station number: 01482800), Chester, Pennsylvania (station number: 01477050), Fort Mifflin, Pennsylvania (station number: 01474703), and the Ben Franklin Bridge, Pennsylvania (station number: 01467200). All data were provided from the United States Geological Survey (USGS) gages (ODRM, 1985).

Chloride concentration (ppt) = A $*$ K

$$A = \frac{0.36996}{\kappa^{-1.07} - 0.7464 * 10^{-3}} \qquad (9)$$

$$K = B_0 + B_1T + B_2T^2 + B_3T^3 + B_4T^4 + B_5T^5 + B_6T^6 \qquad (10)$$

where

κ = conductivity in millisiemens/cm
T= temperature in ℃
$B_0 = 0.13855 * 10$
$B_1 = -0.46485668 * 10^{-1}$
$B_2 = 0.14887785 * 10^{-2}$
$B_3 = -0.63083433 * 10^{-4}$
$B_4 = 0.25144517 * 10^{-5}$
$B_5 = -0.59600245 * 10^{-7}$
$B_6 = -0.57778085 * 10^{-9}$

The location of the salt line is estimated at each station by interpolating between the 7-day average chloride concentrations. Drought conditions or dry periods caused stream flow to decrease. With the effect of low stream flow, chloride concentration increased, the salt line migrated to further upstream, and other stations were used for the interpolation process. To illustrate, if the salt line moves above the river mile (RM) 83, data from Chester (RM 83) and Fort Mifflin (RM 92) USGS water quality gages were used to determine the salt line location. If it migrated to above the Fort Mifflin gage station, data from the USGS monitor at Ben Franklin Bridge (RM 100) was used to determine the location of salt line (Santoro, 2004). River mile locations are depicted in the map at Figure 18.

Figure 18. Map depicting historic salt line locations in the tidal Delaware River and Delaware Bay (DRBC, 2016)

2.5.3. Modeling of the Excess Release Bank

The NYC system uses the excess release bank to store a portion of water to allot for downstream uses. The excess release bank is computed based on the safe yield of the NYC system and the estimated consumption that city must provide from all its sources of supply in each year. Safe yield is given as 1,665 mgd in the Decree, or a total for each year is 607.725 billion gallons. The city consumption set equal to 598.832 billion gallons for each year according to the Office of the Delaware River Master Report. The aggregate quantity of excess release water equals to 83 percent of (607.725 – 598.832), or 7.381 billion gallons or 100 cfs. During the excess release season (defined in the Section 2.2.2), the Montague design target is 1,850 cfs. If the target flow at Montague is higher than the design rate, then the excess release bank does not discharge water for the Montague. Furthermore, if the combined storage of NYC reservoirs is lower than the drought warning line, releases are not made from the excess release bank. The cumulative releases from the excess release bank are computed for each year in the model, and if it exceeds the seasonal quantity, no releases are made from the reservoirs. The releases are become effective at Montague on June 15 until the following March 15, or until the combined storage is equal to or lower than the drought warning line, or until the cumulative releases from the excess release bank becomes equal to seasonal quantity, whichever occurs first. Until 1999, the releases are made based on the drought warning revision 1 in the model, and then it is based on the drought warning revision 4.

Under the emergency drought conditions, the excess release bank were sometimes used to support fish demand and lower basin water requirement in the model. The Docket D-

77-20 CP and its revisions are given in Appendix C, and a detailed explanation of them is placed in Section 3.2.1.

2.5.4. Modeling of the Habitat Bank

After 2002 (Time step: 7788 days), a habitat bank is established in the model to support flow targets for all three tailwaters downstream of the reservoirs. Until 2004 (Revision 7), the flow targets were defined only for the West Branch of the Delaware River at Hale Eddy under the different drought conditions (Table 14). Therefore, a habitat release bank is established in the model only for the Cannonsville Reservoir, and limited to 50 percent of the excess release bank, which is already devoted for fishery releases in the revision 4. As a result, habitat bank releases to support tailwaters at the West Branch of the Delaware River at Hale Eddy are made depending on the specific flow targets under different conditions. If the combined storage is below or at the drought emergency line, then releases from the habitat bank were suspended until the storage of the NYC reservoirs was 25 billion gallon above the drought warning line for 15 consecutive days. Furthermore, if an additional release required to be made, then the other banks are used as explained before. The amounts credited from other banks to habitat bank were established by DRBC and count towards to the habitat bank. Equation (9) shows the habitat bank release schedule from Cannonsville Reservoir. The releases are suspended only if the observed flow at Hale Eddy higher than the flow target, or the cumulative releases from the habitat bank becomes equal to the amount of water established by the DRBC for the habitat bank, whichever occurs first. The habitat releases were added to the demand equation defined in Section 2.4.1. However, these releases are in effect after 2002.

Habitat Releases = IF Hale Eddy Flow (observed) < 225 cfs AND Combined Storage > Normal storage line AND Cumulative Habitat Bank Release <= Habitat Bank THEN Observed Cannosville Release –Thermal Release from Cannonsville –Montague Release from Cannonsville – Conservation Release from Cannosville ELSE IF Hale Eddy Flow (observed) <190 cfs AND Combined Storage <= Normal storage line AND Combined Storage >Drought warning line AND Cumulative Habitat Bank Release <= Habitat Bank THEN Observed Cannosville Release –Thermal Release from Cannonsville –Montague Release from Cannonsville – Conservation Release from Cannosville ELSE IF Hale Eddy Flow (observed) <150 cfs AND Combined Storage <=Drought warning line AND Combined Storage > Drought line AND Cumulative Habitat Bank Release <= Habitat Bank THEN Observed Cannosville Release –Thermal Release from Cannonsville – Montague Release from Cannonsville – Conservation Release from Cannosville ELSE IF Combined Storage <Drought line THEN 0 ELSE 0 (11)

Due to the limitations in the STELLA as explained before, the simulated outflow of reservoirs cannot be used in the model. Thus, the observed/actual historical release data used in the Equation (11).

In 2004 (Time step: 8545 days) with the approval of the Revision 7, a revised habitat bank is established in the model. The bank consists of a thermal release bank, an excess release bank, and a supplemental release bank. In the model, releases from the NYC reservoirs are regulated under different conditions as indicated in Table 15. In case of the drought watch and the drought warning conditions, the remaining quantity of water in the thermal release bank and the supplemental release bank are reduced by 15 percent. Under the drought conditions, these releases are suspended until the combined storage is 25 billion gallons above the drought watch line for 15 consecutive days. Moreover, if the habitat bank is exhausted, the reference releases (Table 16) are used as conservation releases. In the event that the combined excess release bank and the supplemental release bank are exhausted, flow targets set equal to zero in the model, and conservation releases are made based on the basic conservation releases shown in Table 10. The revisions for the habitat bank releases were explained in Section 3.2.5., and the original revisions established by the DRBC are available in Appendix C.

3. METHODOLOGY

3.1. Storage in the New York City Reservoirs

The total combined storage capacity of the NYC reservoirs is 271 BG. They operated to meet various flow objectives and diversion schedules. All are located in the headwaters of the Delaware Basin. Table 9 summarizes the reservoir levels and contents of Pepacton, Cannonsville and Neversink (ODRM, 1999). Figure 19 illustrates the location of NYC reservoirs.

Figure 19. Location of NYC reservoirs in the Delaware River Basin (DRBC, 2016)

The largest impound among the upper basin reservoirs is Pepacton which holds 140 billion gallons of water at full capacity. The reservoir is approximately 17 miles long, and the mean depth is approximately 74 feet. The drainage area of the reservoir is 371 square miles (NYCEP, 2017a).

The usable storage capacity of the Cannonsville Reservoir, between the spillway crest elevation (1,150.00 ft.) and lowest recorded elevation (1,035.00 ft.), is approximately 96 billion gallons, or 297 acre – feet. The reservoir is approximately 12 miles long, and the mean depth is approximately 61 feet, which is relative to the spillway crest elevation (Cornell University, 1982). The drainage area of the Cannonsville Reservoir is 455 square miles.

The Neversink Reservoir's usable storage capacity is relative to the spillway crest elevation (1,440.00 ft.). It is approximately 35 billion gallons, or 108,841 acre – feet, and it represents the storage volume between the spillway crest elevation and lowest recorded elevation (1,314.00 ft.). The reservoir is approximately 5 miles long, and the mean depth is 72 feet. The drainage area of the Neversink Reservoir is 92 square miles (NYCEP, 2017).

Table 9. Elevation and Storage in NYC reservoirs at different reservoir levels

Reservoir Level	Pepacton		Cannonsville		Neversink	
	Elev (feet)	Contents (bg)	Elev. (feet)	Contents (bg)	Elev. (feet)	Contents (bg)
Full pool or spillway crest	1,280.00	*140.190	1,150.00	*95.706	1,440.00	*34.941
Point of max depletion	1,152.00	*3.511	1,040.00	*1.020	1,319.00	*0.525
Sill of diversion tunnel	1,143.00		1,035.00		1,314.00	
Sill of river outlet tunnel	1,126.00	*4.200	1,020.5	*1.564	1,314.00	
Dead storage		1.800		0.328		1.680

*Contents shown are quantities stored between listed elevations

The timing and magnitude of releases is based on the schedule of conservation flow releases, NYC water supply diversion, and directed releases for the Montague flow target. Based on daily releases and spills, the amount of water in storage is subjected to change. The natural hydrology of the area also affects the reservoir storage. During the late winter/early spring months, there is rainfall activity that causes reservoir volume to increase. During summer/early fall months, there is much less rain activity that results in reservoirs to lose water (The U.S. Army Corps of Engineers, 1981).

The daily storage data used in the model for each reservoir is taken from The Office of the Delaware River Master Report for the period of 1980 to 2005. The sum of the daily storage of each reservoir is called combined storage in the model, and it is linked to the operation rule curve.

3.2. Development of Design Based on Historical Reservoir Operations

3.2.1. Excess Release Bank

The 1954 Decree introduced an excess release bank of storage water, to be released for various purposes, such as fishery protection, increasing the Montague flow objective during seasonal periods of high demand, or responding to the lower basin drought management plan. On the basis of the 1954 Decree, excess release bank is calculated based on the excess quantity of water which is explained in Section 2.5.3. Excess releases from each of the three reservoirs began each year on June 15, and the design rate for that period became effective at that date. The excess release quantity was released at rates designed to maintain the Montague target flow at 100 cfs above the normal 1,750 cfs specified by the 1954 Decree. Excess releases were limited according to the reservoir storage curve and design rate at Montague. If the combined storage of all three NYC reservoirs reduced to drought warning or drought levels, reservoirs would not release water from the excess release bank (DRBC, 1977; ODRM, 2016). The D-77-20 CP and its revisions established by the DRBC for excess release bank are given in Appendix C.

In 1981, due to drought emergency conditions, release of the excess quantity was deferred by the River Master after an unanimous request of the representatives of parties to the Decree and the DRBC to conserve water in NYC reservoirs. Therefore, the excess releases were not made from the reservoirs during the year. Furthermore, due to deficient precipitation and runoff in 1982, equivalent to a drawdown in the Beltzville Reservoir, the design rate at Montague was lowered from 1,850 cfs to 1,750 cfs during most weekdays to conserve storage in NYC reservoirs. The release contributed to flows in Delaware River at Trenton (ODRM, 2016).

In 1987, due to extraordinary hydrologic conditions in the upper Delaware River Basin, there were high demands upon the available thermal release bank. Therefore, 3,000 cfs-days from the excess release quantity were used for fishery protection, and the excess release quantity of 11,418 cfs was reduced to 8,418 cfs. If 3,000 cfs-days were not expended by September 30, 1987, the remaining part became available for excess release credits (DRBC, 1987). Similarly, in 1990, because the original 6,000 cfs –days thermal release bank was exhausted, an additional 2,000 cfs-days were used from the excess release bank. Thereby, the excess release quantity of 11,418 cfs-days was decreased to 9,418 cfs-days, and if it was not expended by September 30, 1990, the remaining part were credited to the excess release bank (DRBC,1990).

3.2.2. Conservation Releases

The Supreme Court Decrees of 1931 and 1954 did not include provisions for minimum conservation releases. Therefore, in 1977, the New York State Department of Environmental Conservation issued regulations that require minimum releases from Cannonsville, Pepacton, and Neversink Reservoirs to maintain some small flow in the upper Delaware for conservation purposes. Consequently, the basic conservation release schedule was established after the claims of riparian landowners to the New York State

Supreme Court (DRBC, 1977; DRBC, 2017).

New York State, with the agreement of NYC, proposed a two-year experimental program that reservoir releases were based on augmented conservation release schedules for the purpose of enhancing the downstream of fishery below each of the three NYC reservoirs. In DRBC Docket D-77-20 CP, a new schedule of augmented conservation releases was established for all three reservoirs. The augmented releases ranged from 25 cfs to 70 cfs, with a two month summer release of 325 cfs from Cannonsville Reservoir (Table 10).

On November 30, 1983, the original 1977 docket (Docket D-77-20 CP) revised by the approval of DRBC, and augmented release schedule became permanent. This revised plan linked the augmented and basic releases to a basin wide drought-operating plan. During periods of drought warning and drought emergency, as defined by the operating rule curves, conservation releases were reduced to basic releases. When combined storage was reached to 25 billion gallons (bg) above the drought warning level and remained 15 consecutive days at or above that level, releases were returned to the normal augmented levels again. Furthermore, if combined storage were lower than the drought warning line and remained 5 consecutive days at or below that level, drought emergency operations would be considered (DRBC, 2008). With this revision, the NYDEC (New York State Department of Environmental Conservation) evaluations found that the program improved and extended the trout fisheries downstream of all three reservoirs (DRBC, 1983, DRBC, 2017).

In order to further protect and enhance recreational use of water, summer augmented releases from Neversink and Pepacton were revised under the temporary revision of Docket D-77-20 CP (Revised) on June 23, 1993. The revised release rates are shown in

Table 10. Because a new conservation release valve had not been installed, the release rates from Cannonsville were not revised in Revision 2. In 1997, with the completion of Cannonsville conservation release valve, DRBC approved the third revision of the docket, which includes the adjusted experimental conservation release rates from Cannonsville. The maximum release was reduced to 160 cfs from 325 cfs, the time during the release was extended from June 1 through September 15, and the release rate was decreased to 45 cfs on September 16 (Table 10).

In 1999, revision 4 was approved by the DRBC. It raised the drought warning line by 4 billion gallons, and divided it into two different stages. The upper half of the drought warning line was named as drought watch while lower half was maintained as the drought warning. Conservation releases from the NYC reservoirs were decreased to 85 percent of the augmented release level during drought watch conditions. On April 3, 2002, with the approval of Revision 5, the minimum releases from the Cannonsville Reservoir were temporarily modified based on the drought stages defined in operating rule curves, which was revised in Revision 4. It was reaffirmed on March 19, 2003 with the approval of Revision 6 by the DRBC. Table 11 shows the specific releases from the Cannonsville reservoir (DRBC, 1999). The releases from the NYC reservoirs were made based on the basic conservation release schedule under the drought and drought warning conditions while augmented and experimental conservation release schedule were used under the normal conditions. The augmented and the experimental conservation release schedule were established in the Docket D-77-20 CP, and the Docket D-77-20 CP Revision 2, respectively. The Docket D-77-20 CP, and the Docket D-77-20 CP Revision 2 is available in Appendix C.

Table 10. Schedule of Minimum Releases from the Cannonsville, Pepacton, and Neversink (DRBC, 2017)

<table>
<tr><th>Reservoir and Operative Dates</th><th>Basic Conservation Releases cfs</th><th>Augmented Conservation Release[a] cfs</th><th>Experimental Conservation Release[b] cfs</th></tr>
<tr><td colspan="4">Neversink</td></tr>
<tr><td>1/1 – 3/31</td><td>5</td><td>25</td><td>25</td></tr>
<tr><td>4/1 – 4/7</td><td>5</td><td>45</td><td>25</td></tr>
<tr><td>4/8 – 4/30</td><td>15</td><td>45</td><td>25</td></tr>
<tr><td>5/1 – 9/30</td><td>15</td><td>45</td><td>53</td></tr>
<tr><td>10/1 – 10/31</td><td>15</td><td>45</td><td>25</td></tr>
<tr><td>11/1 – 12/31</td><td>5</td><td>25</td><td>25</td></tr>
<tr><td colspan="4">Pepacton</td></tr>
<tr><td>1/1 – 3/31</td><td>6</td><td>50</td><td>45</td></tr>
<tr><td>4/1 – 4/7</td><td>6</td><td>70</td><td>45</td></tr>
<tr><td>4/8 – 4/30</td><td>19</td><td>70</td><td>45</td></tr>
<tr><td>5/1 – 5/31</td><td>19</td><td>70</td><td>70</td></tr>
<tr><td>6/1 – 8/31</td><td>19</td><td>70</td><td>95</td></tr>
<tr><td>9/1 – 9/30</td><td>19</td><td>70</td><td>70</td></tr>
<tr><td>10/1 – 10/31</td><td>19</td><td>70</td><td>45</td></tr>
<tr><td>11/1 – 12/31</td><td>6</td><td>50</td><td>45</td></tr>
<tr><td colspan="4">Cannonsville</td></tr>
<tr><td>4/1 – 4/15</td><td>8</td><td>45</td><td rowspan="2">4/1 – 5/31: 45</td></tr>
<tr><td>4/16 – 6/14</td><td>23</td><td>45</td></tr>
<tr><td>6/15 – 8/15</td><td>23</td><td>325</td><td rowspan="2">6/1 – 9/15: 160</td></tr>
<tr><td>8/16 – 10/31</td><td>23</td><td>45</td></tr>
<tr><td>11/1 – 11/30</td><td>23</td><td>33</td><td rowspan="2">9/16 – 3/31:45</td></tr>
<tr><td>12/1 – 3/31</td><td>8</td><td>33</td></tr>
</table>

a D-77-CP

b D-77-CP Revision 2 and Revision 3

Table 11. Conservation Releases for the Cannonsville Reservoir (DRBC, 2002a)

Operating Conditions	Release Rate (cfs)
Normal	45
Drought Watch	35
Drought Warning	23
Drought Emergency	8-23*

* Basic Release Schedule for the Cannonsville Reservoir in the Table 10.

Necessary provisions of Revision 2 through the Revision 6 were incorporated into Revision 7 to establish an experimental augmented conservation release program for the New York City Delaware River Basin Reservoirs between the period beginning May 1, 2004 and ending May 31, 2007. The minimum summer releases were reduced in Revision 7 compared to the Revision 4 conservation release schedule. The differences between the releases from Revision 7 and the reference releases established in the Revision 7 were debited or credited to habitat protection bank. However, a negative balance in the habitat protection bank was not allowed. Minimum conservation releases established by the Revision 7 for all three New York Reservoirs are shown in Table 12. The revisions for the conservation releases are given in Appendix C.

Table 12. Conservation Releases (DRBC, 2004a)

Reservoir	Conservation Release (cfs)			
	Normal	Drought Watch	Drought Warning	Drought
Cannonsville(9/1 – 5/31)	45	38	32	23
Cannonsville (6/1 – 8/31)	60	51	43	23
Pepacton	35	30	25	19
Neversink	25	21	18	15

Furthermore, the conservation releases would be made as specified in Table 13 if banks were exhausted and targets were not able to be met.

Table 13. Reference Conservation Releases

Reservoir and Operation Dates	Release Rates (cfs)			
	Normal	Drought Watch	Drought Warning	Drought
Cannonsville				
1/1 – 4/15	45	38	8	8
4/16 – 5/31	45	38	23	23
6/1 – 9/15	160	136	23	23
9/16 – 11/30	45	38	23	23
12/1 – 12/31	45	38	8	8
Pepacton				
1/1 – 4/7	45	38	6	6
4/8 – 4/30	45	38	19	19
5/1 – 5/31	70	60	19	19
6/1 – 8/31	95	81	19	19
9/1 – 9/30	70	60	19	19
10/1 – 10/31	45	38	19	19
11/1 – 12/31	45	38	6	6
Neversink				
1/1 – 4/7	25	21	5	5
4/8 – 4/30	25	21	15	15
5/1 – 9/30	53	45	15	15
10/1 – 10/31	25	21	15	15
11/1 – 12/31	25	21	5	5

3.2.3. Montague Target Flow

The U.S. Supreme Court decree provided for locating a gaging station in Montague, New Jersey to monitor the minimum flow requirements at the location. The data and computations of the various components of flow form the basic operational records to carry out specific responsibilities for the Montague formula (NYCDEP, 1974). The computation of the direct releases from the NYC reservoirs is explained in Section 2.5.2.3. There were also some exceptions for release schedules to maintain the Montague flow target during 24 years of operation. These exceptions are explained in detail in Appendix B.

3.2.4. Thermal Stress Releases

In order to relieve thermal stress conditions, which result in a threat to fisheries, special releases were made from NYC reservoirs. The releases were made whenever the maximum water temperature at designed downstream USGS gaging stations defined in Section 2.5.2.2. exceeded a maximum of 75 °F. The total volume of these releases was restricted to 6,000 cfs-days, and it was not used after November 1st to April 30 of any year. Also, thermal releases were made if the combined storage of NYC reservoirs was above the drought warning level. However, from 1981 until 1983, it was limited with the total volume of excess release bank. If the total volume of augmented releases and thermal stress releases exceed the total quantity in the excess release bank, no releases would be made, except the minimum basic flow at Montague. Releases required to maintain minimum flow at Montague or required under the basic releases schedule when releases were not directed to maintain the minimum target flow at Montague of 1750 cfs were not be counted against the excess release bank (DRBC, 1977).

In 1984, below normal precipitation from August to November coupled with large releases to maintain the Montague flow target and diversions for water supply resulted in decreasing the storage in the reservoirs to drought warning level. As of August 15, approximately 85 percent of the available water stored for the thermal release bank was released. However, water in excess of the amount remaining in the thermal stress release bank was required to relieve thermal stress on the fisheries in the river downstream of NYC reservoirs. Therefore, DRBC approved Resolution 84-22 to allow temporarily additional thermal stress releases in excess of the 6,000 cfs-days limit. Based on the resolution, the thermal stress release was increased by 3,000 cfs-days in addition to 6,000 cfs-days until September 30, 1984. Additional releases were subjected to the condition that the combined storage of all three NYC reservoirs remains at 60 million gallons over the upper limit of the drought warning line (DRBC, 1984).

On July 27, 1985, with the approval of DRBC Resolution No. 85 – 21 (revised), the Montague target flow depended on the time of year and location of salt line during drought warning conditions. Reservoir releases were decreased as defined in Section 2.2.4 to maintain the Montague flow target due to the reduction of the Montague flow objective. Thereby, 25 percent of savings in storage achieved by reduction of the Montague flow objective were allocated to the thermal emergency bank. In addition, DRBC established a thermal emergency bank of 2,000 cfs-days during the period of July 5 to July 24, 1985. Then, Conservation Order No. 7, which was enacted July 24, 1985, established an additional 1,500 cfs-days thermal bank releases to prevent possible fish kills; as a result, a total thermal emergency bank of 3,500 cfs-days was established, and these releases were credited by reducing the Montague flow objective.

In 1987, during June and July, conditions in the upper Delaware River Basin resulted in an unusually high demand on the thermal stress relief bank provided for in the Interstate Water Management Recommendations of the Parties to the 1954 Decree. On August 5, at the request of New York State, the parties to the Decree and the Delaware River Basin Commission agreed to set aside 3,000 cfs-days from the excess release quantity to be used for thermal stress release in addition of 6,000 cfs-days until September 30, 1987 (DRBC, 1987). Furthermore, On August 8, 1990, New York State requested again an additional 2,000 cfs–days of the excess release quantity to be used for the purposes of thermal protection due to extraordinary hydrological conditions in the basin. 9,000 cfs-days of thermal stress bank were used until September 30, 1990 (DRBC, 1990).

On April 28, 1999, Revision 4 provided that, for the duration of the revision, one half of the excess release quantity was allocated for the purpose of fishery protection. Approximately 5,400 cfs-days were available for the fishery protection bank during drought warning conditions (DRBC, 1999). On August 16, 2000, a special meeting was held between the Delaware River Master Advisory Committee, the New York State Department of Environmental Conservation and the New York City Department of Environmental Protection to provide additional releases from Cannonsville Reservoir to maintain a minimum daily flow of 200 cfs at Hale Eddy USGS station, N.Y. Therefore, up to an additional 40 cfs each day between August 28 and September 15, and an additional of 155 cfs between September 16 and October 31 were established by the DRBC Resolution No. 2000 – 14. These additional releases were charged against to Special Thermal Stress Bank established as 6,000 cfs-days, and never made if there was adequate water to maintain a minimum daily flow of 200 cfs at Hale Eddy, NY. This program was in effect until October 31, 2000 (DRBC, 2000).

With the establishing of a temporarily habitat bank in Revision 5, half of the 5,700 cfs-days were devoted to thermal releases to protect fisheries downstream of the reservoirs. Also, thermal stress bank releases was reduced by 15 percent during drought watch conditions, and suspended during drought warning conditions. If combined storage of all three NYC reservoirs was 25 billion gallons above the drought watch line for 15 consecutive days, thermal releases were returned back to normal operating conditions (DRBC, 2002a). On July 17, 2002, the Revision 5 (amended) approved, and the total quantity of water in the thermal release bank was explicitly defined. The 9,200 cfs-days the thermal release bank were credited on May 1, 2002 until April 30, 2003 (DRBC, 2002b).

3.2.5. Habitat Bank

To support of experimental flow targets on the West Branch of the Delaware River at Hale Eddy, NY, and modified the minimum releases from the Cannonsville Reservoir (Table 14), a temporarily habitat bank is established on April 3, 2002. The 5,700 cfs-days of habitat bank consisted of half of the excess release quantity releases that is already temporarily devoted for fishery production under the revision 4. The remaining part of the excess release bank continued to be available to benefit down basin users (in order to maintain the Montague flow target) or it was banked in accordance with a lower basin drought management plan. The habitat bank was used only to meet the target flows in the West Branch Delaware River at Hale Eddy until the revision 7. Table 14 shows the habitat bank flow targets in the West Branch Delaware River at Hale Eddy. The difference between the habitat bank and conservation releases under the revision 5 were debited or credited to the habitat bank. The revision did not allow a negative balance in the habitat bank (DRBC, 2002b).

Table 14. The flow targets in the West Branch Delaware River at Hale Eddy (DRBC, 2002b)

Storage Conditions in the Reservoirs	Release Rate (cfs)
Normal	225
Drought Watch	190
Drought Warning	150

In July 2002, the Revision 5 (amended) was approved by the DRBC. It allowed using the habitat bank releases to augment flows at specified locations on the tributaries below NYC reservoirs. (DRBC, 2002c). These locations were the West Branch, Delaware River at Hale Eddy, East Branch Delaware River at Harvard, and the Neversink River at Bridgeville. However flow targets did not established until the Revision 7. Revision 6 was also approved in 2003. The habitat bank in the revision 6 consisted of 4,567 cfs-days, which was contributed for one year only from the excess release bank. Water from the excess release bank not assigned for the habitat bank was used for the Montague flow target.

Revision 7 was established an interim reservoir release program to maintain target flows in the tailwaters below the City reservoirs. It established a 20,000 cfs-day of the habitat protection bank, which consists of excess release bank (5,700 cfs-day), thermal release bank (9,200 cfs-days), and supplemental release bank (5,100 cfs-days). The aim of the habitat protection bank was to protect habitat and fisheries of tailwaters below each of NYC reservoirs. Upon entry into drought watch, and drought warning, the remaining quantity of water in the thermal release bank and the supplemental release bank were reduced by 15 percent. In case of drought conditions, releases from the thermal release bank and the supplemental release bank were suspended. If the combined storage were 25 billion gallons above the drought watch for 15 consecutive days, then releases will be in effect. The revised habitat bank releases are shown in Table 15 for the downstream of NYC reservoirs. These releases were made if the combined storage in the City reservoirs were 25 billion gallons above the drought warning line for 15 consecutive days. The revisions for the habitat bank is illustrated in Appendix C.

Table 15 Habitat Protection Bank Flow Targets (DRBC, 2004b)

Target Location	Flow Target			
	Normal	Drought Watch	Drought Warning	Drought
West Branch Delaware R at Hale Eddy	225	190	160	145
East Branch Delaware R at Harvard	175	150	120	115
Neversink River at Bridgeville	115	100	80	75

3.2.6. Diversion to New York City Water Supply

Construction of the Delaware River System was begun in 1937 after the Supreme Court of The United States approved the diversion of water to NYC in order to augment its water supply from the headwaters of the Delaware River. After construction of the Delaware Aqueduct in 1944, the Rondout Reservoir in 1950, the Neversink Reservoir in 1954, the Pepacton Reservoir in 1955, and the Cannonsville Reservoir in 1964, the Delaware River System was placed in service (NYCEP, 2017b).

With the 1954 Amended Decree, NYC was authorized to divert water from the Delaware River Basin at a rate not to exceed 800 MGD (as an annual average). The Decree also ruled that the rate of diversions would be computed as the aggregate total diversion beginning on June 1st of each year divided by the number of days elapsed since the preceding May 31st (Supreme Court of the U.S., 1954).

In 1983, with the implementation of the Interstate Water Management Recommendations of the Parties to the Decree, diversions by NYC from the Delaware River Basin reservoirs were limited based on a formula, which differentiate normal, drought warning, and drought conditions depending on combined storage levels shown in Figure 5. Table 16 illustrates the interstate operation formula for reductions in diversions to NYC during periods of drought. Later in 1999, the upper half, and lower half were named in the Revision 4 as drought watch and drought warning, respectively.

Table 16. Interstate Operation Formula for Reductions in Diversions to NYC (IWMR, 1983)

NYC Storage Condition	NYC Diversion (mgd)
Normal	800
Upper Half – Drought Warning	680
Lower Half – Drought Warning	560
Drought	520

During drought warning and drought conditions, NYC diversion is computed as a daily running average. If the combined storage of the NYC Delaware Basin reservoirs declines the drought warning line, and remains below that line for five consecutive days, the drought warning operations become effective until the combined storage reaches a level 15 billion gallons above the drought warning line at which time normal operations would be resumed. For drought emergency declaration, the combined storage of NYC reservoirs falls into the drought zone for 5 consecutive days (DRBC, 2008).

The East Delaware Tunnel is used to supply water from the Pepacton Reservoir to the Rondout Reservoir for water supply to NYC. The capacity of the tunnel is 585 MGD (NJDEP, 2014). A hydroelectric power plant at the downstream end of the East Delaware Tunnel is operated with diverted water (ODRM, 2016).

Water is diverted to the Rondout Reservoir from the Cannonsville Reservoir through 500 MGD capacity of the West Delaware Tunnel (NJDEP, 2014). A hydroelectric power plant uses water diverted by the tunnel. The power plant only operates if the diversions are more than 300 MGD.

Another source of water for the Rondout Reservoir is the diversions from the Neversink Reservoir through the Neversink Tunnel. The capacity of the tunnel is 390 MGD

(NJDEP, 2014). The hydroelectric power plant utilizes the water diverted by the Neversink Tunnel.

The City of New York recorded the diversions through the East Delaware, the West Delaware, and the Neversink Tunnel, and then they report the daily total flows to the River Master's office on a daily basis. The daily water diversion data used in the model is taken from the Delaware River Master Report for the period of between 1980 and 2005 (ODRM, 2016). The data is between December 1st,1980 and November 30, 2005. The 24 years of daily diversions to NYC water supply are implemented into the model as a function of time. A map of water diversion from three reservoirs to NYC is illustrated in Figure 20.

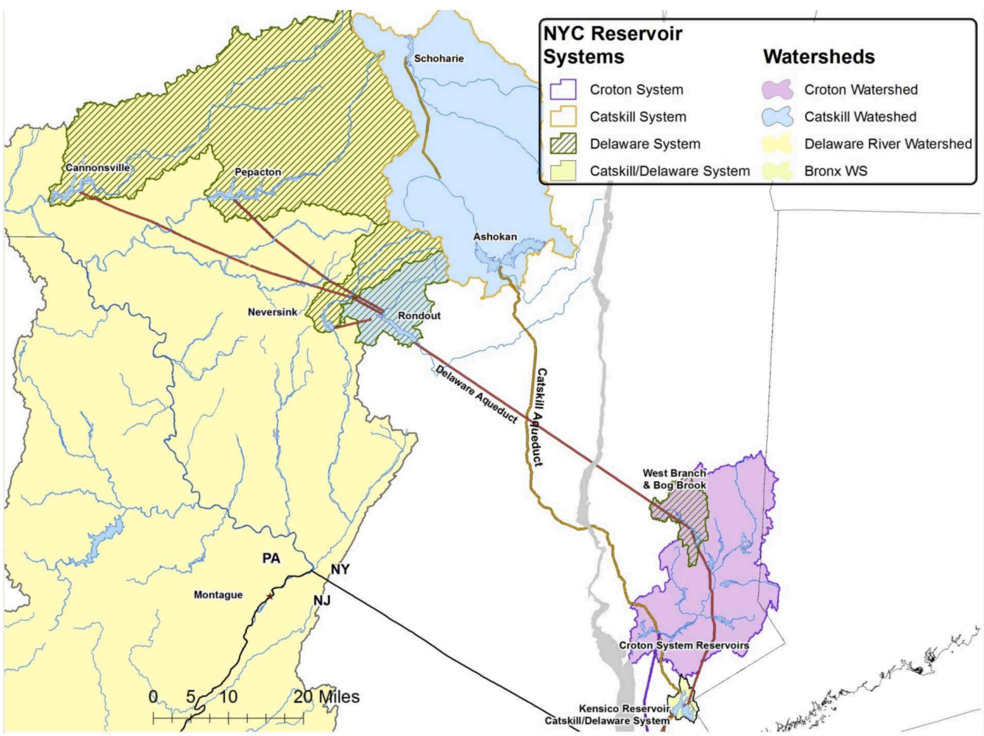


Figure 20. New York City Water Diversion from The Delaware River Basin NYC Reservoirs (NJDEP, 2014a)

4. MODEL RESULTS

The historical streamflow and precipitation, and reservoirs operation parameters were employed to generate results from the NYC STELLA model. The generated and actual historical outflow and storage for each reservoir were visually compared and verified for accuracy. Figure 21, Figure 22, and Figure 23 show observed and modeled outflows for fifteen year simulation (1980 – 1995) for Cannonsville, Pepacton and Neversink reservoirs, respectively. The model was run for fifteen years due to a lack of data to calculate the Montague flow target.

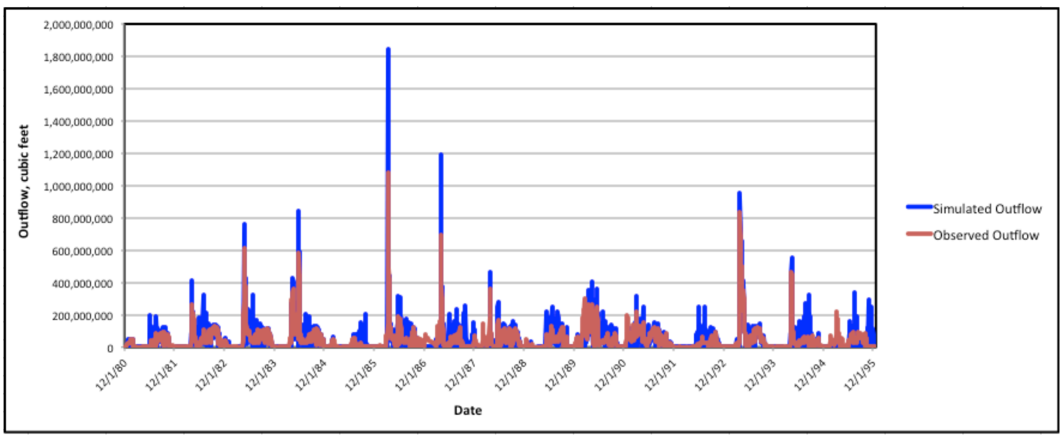


Figure 21. Observed versus Modeled Outflow for Cannonsville Reservoir

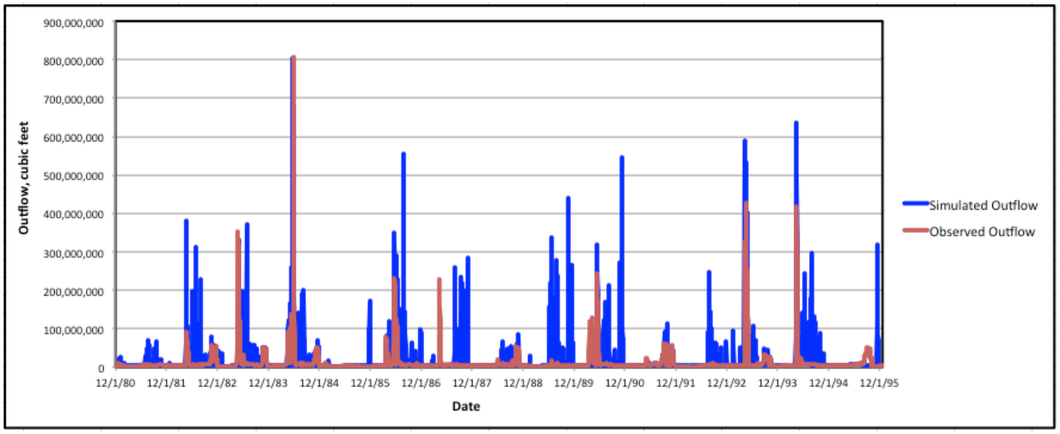


Figure 22. Observed versus Modeled Outflow for Pepacton Reservoir

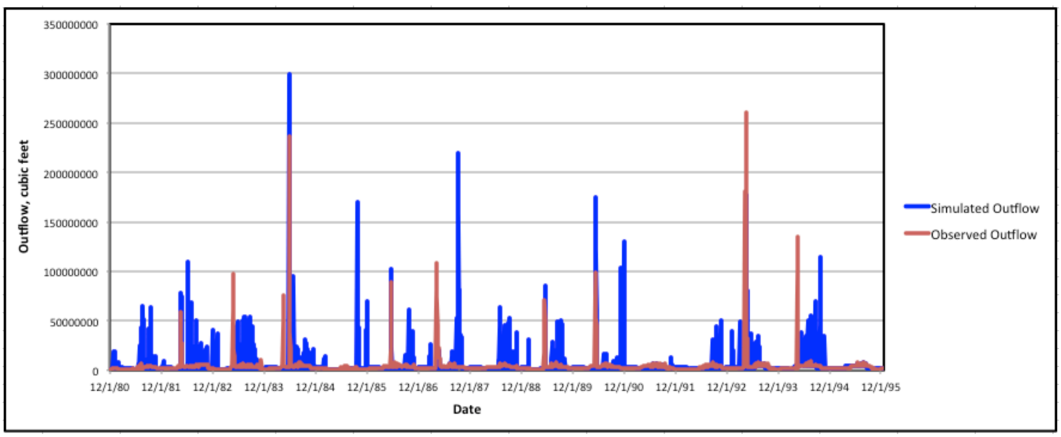


Figure 23. Observed versus Modeled Outflow for Neversink Reservoir

Figure 24 indicates the years that drought emergency in the basin was declared by the DRBC. Throughout fifteen years, only four times a state of emergency was declared due to drought in the Delaware River Basin. As seen from Figure 21, Figure 22 and Figure 23, during the drought emergency, releases from each reservoir were made for minimum conservation purposes (based on the basic release schedule). The releases only be returned to the augmented levels after the combined storage reached to 25 BG above the drought warning level and remained there for 15 consecutive days. Inflows to the reservoirs generally exceed draft rates during the December through May, and thereby increase the reservoir's storage (Figure 25, Figure 26, and Figure 27).

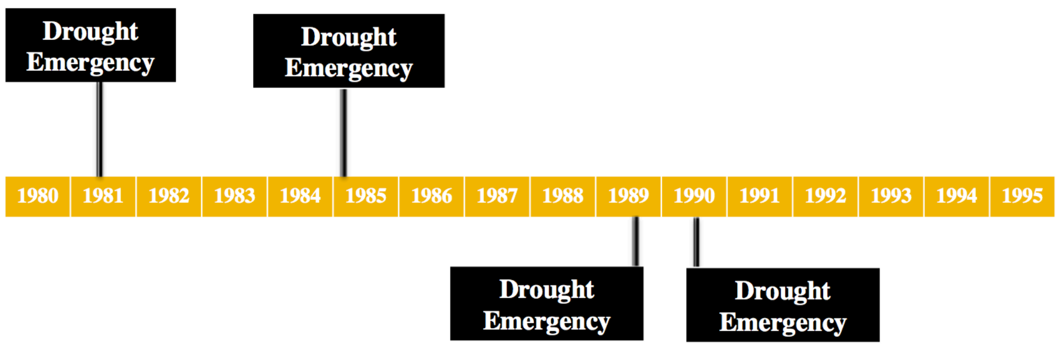


Figure 24. Drought Emergency Conditions for the Delaware River Basin from 1985 to 1995

In 1982, the precipitation in April was the greatest for the month in the record, thus all three reservoirs were spilling before the month ended. In 1986, the combined storage was increased to capacity during the winter months, and thus all three reservoirs spill.

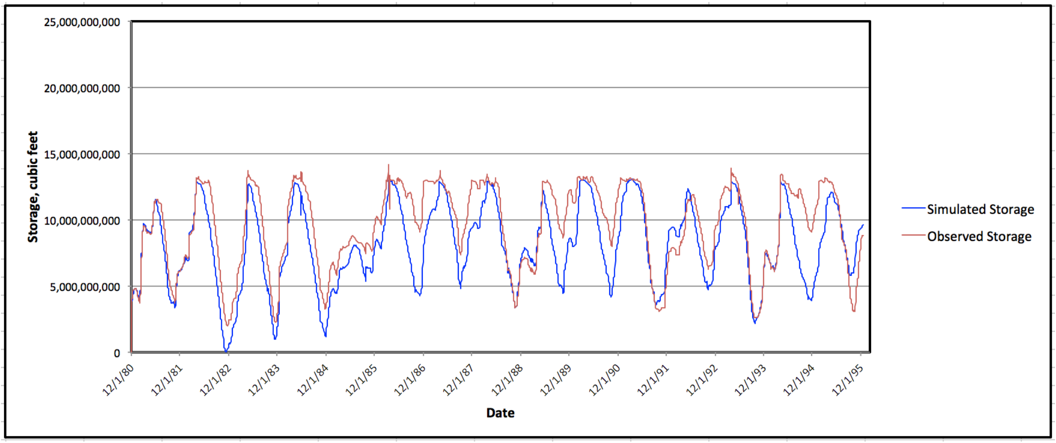


Figure 25. Observed versus Modeled Storage for Cannonsville Reservoir

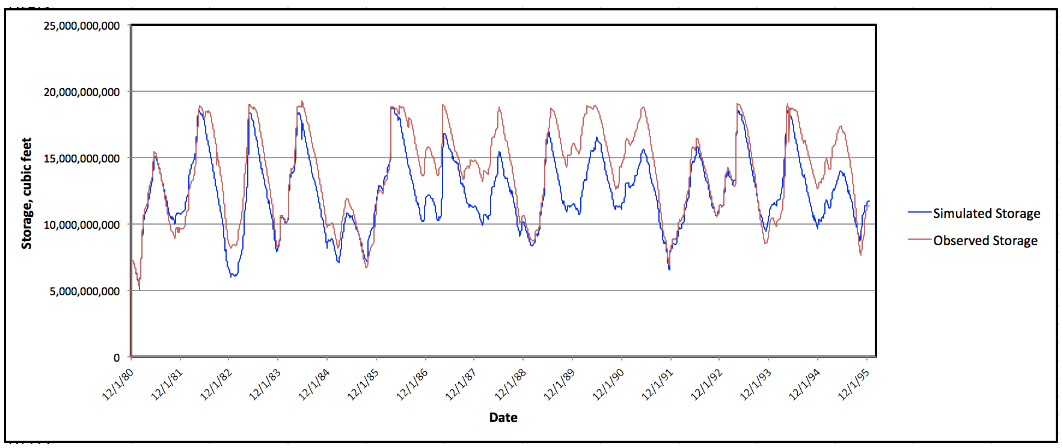


Figure 26. Observed versus Modeled Storage for Pepacton Reservoir

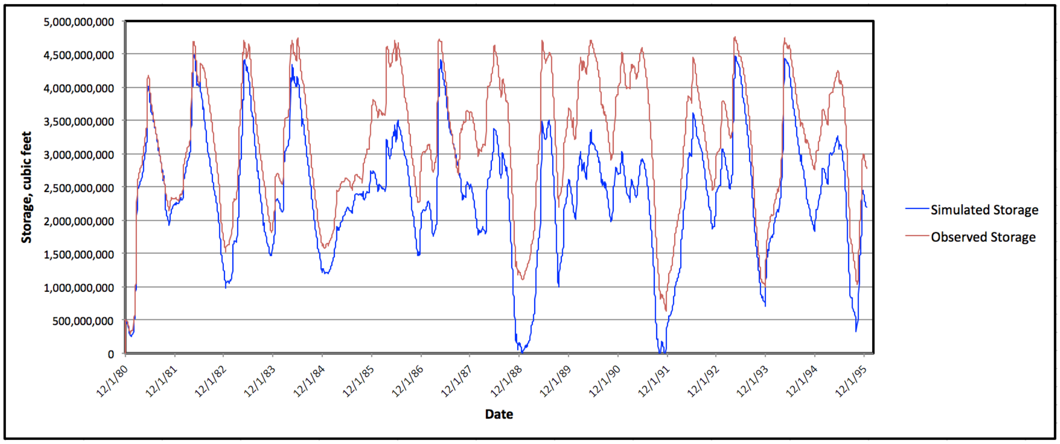


Figure 27. Observed versus Modeled Storage for Neversink Reservoir

In 1993, throughout August and September, the precipitation decreased significantly, therefore storage continued to decline above normal rates. Combined storage of NYC reservoirs fall below the drought warning level of the operation curves on September, and the release rates were reduced based on the IWMR.

Even though the model followed observed data have similar trend for the storage of the each reservoir, the model spills more water comparing to actual data. This might be the result of large inflows into the reservoirs. Therefore, estimated inflow through DRB-SET and recorded data by USGS along with the precipitation is compared with actual inflow by calculating it via mass balance. To calculate the inflow, the daily actual storage data is subtracted from the outflow (reservoir releases and NYC diversion) for each reservoir. Figure 28, Figure 29, and Figure 30 illustrate the comparison of estimated inflow by using DRB-SET tool and calculated inflow by using actual data. Based on the figures, the inflow data trend used in the model is very close to the actual inflow data calculated through mass balance.

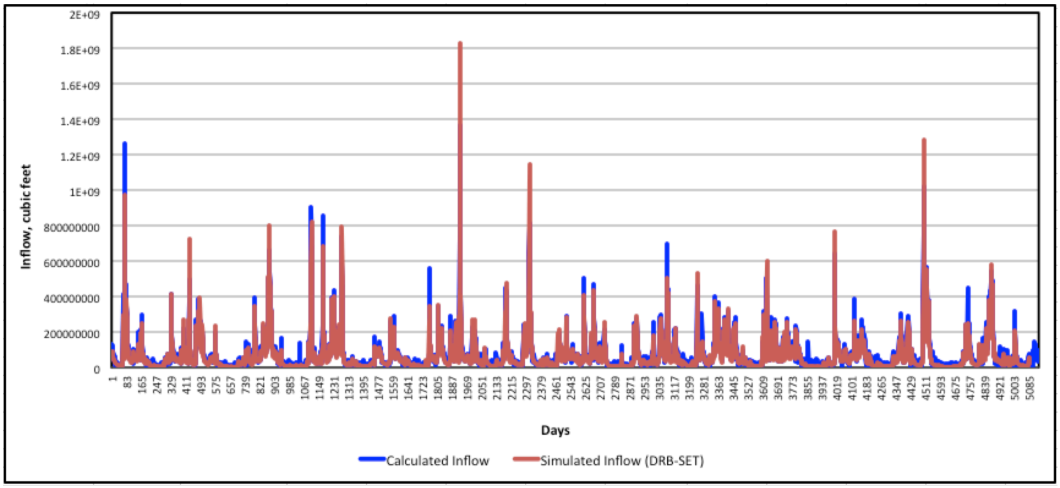


Figure 28. Estimated versus Calculated Inflow for Cannonsville Reservoir

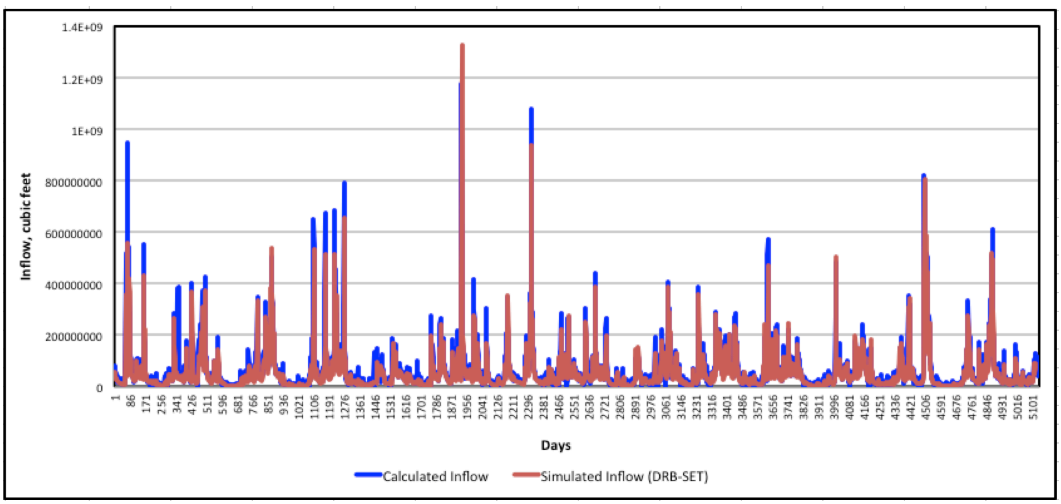


Figure 29. Estimated versus Calculated Inflow for Pepacton Reservoir

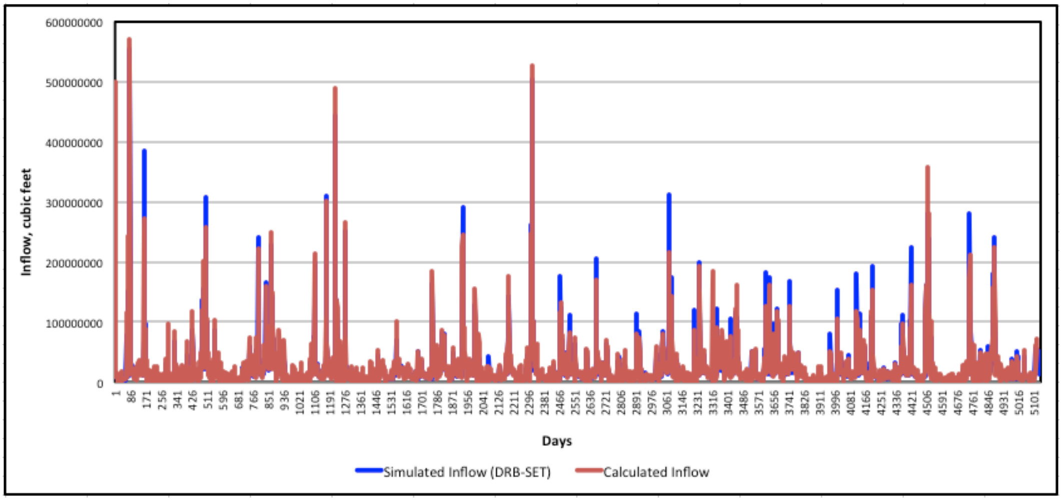


Figure 30. Estimated versus Calculated Inflow for Neversink Reservoir

The seasonal reservoir operation zone determines the spill from the reservoirs depending on the volume of water inside the reservoir, and it is calculated based on the long-term median storage on the basis of 23 years of reservoir storage records, as explained in Section 2. To determine why reservoirs spill more water than actual, the observed daily storage records compared with the long-term median storage for each reservoir (Figure 31, Figure 32 and Figure 33). According to the figures, there are days that actual reservoir storage is above the long-term median storage, and reservoirs do not spill. However, the model spills if the storage is higher than the long-term median.

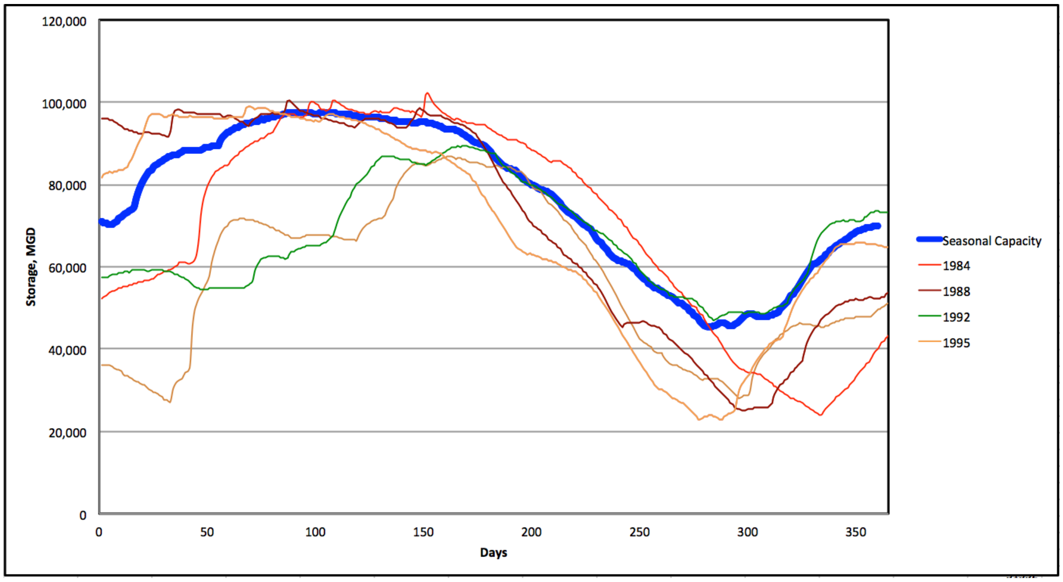


Figure 31. Actual daily storage versus long-term median storage for Cannonsville Reservoir

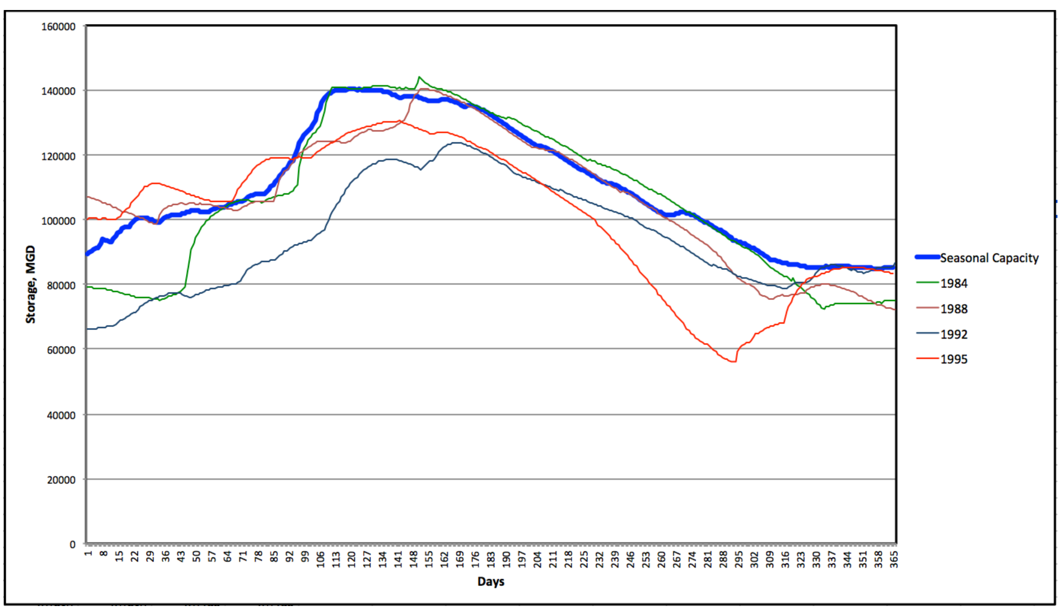


Figure 32. Actual daily storage versus long-term median storage for Pepacton Reservoir

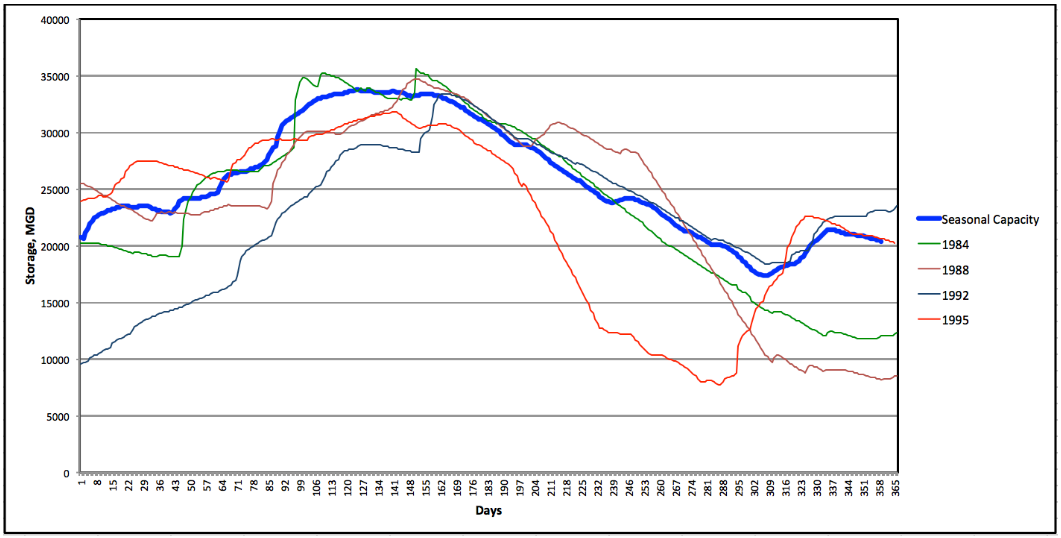


Figure 33. Actual daily storage versus long-term median storage for Neversink Reservoir

To determine if there are statistically significant differences between each year and the long-term median seasonal capacity, a non-parametric statistical analysis was done with 95% confidence limits. Table 15 summarizes the results for three reservoirs. As indicated the table, the difference between actual storage data and the long-term median of seasonal capacity for each reservoir is statistically not significant. Therefore, the seasonal operation zone approach is used in the model to represent an amount of seasonal storage in the reservoirs. This approach provides a guidance to determine of the amount of storage available for downstream purposes and recreational use of the reservoirs.

Table 17. Comparison of actual storage data for each year and the long-term median seasonal capacity for three reservoirs

Years	Cannonsville	Pepacton	Neversink
	Significance		
1981	0.152	0.175	0.319
1982	0.175	0.168	0.321
1983	0.220	0.199	0.333
1984	0.163	0.170	0.319
1985	0.276	0.187	0.321
1986	0.173	0.182	0.320
1987	0.213	0.183	0.320
1988	0.181	0.158	0.321
1989	0.142	0.262	0.425
1990	0.193	0.202	0.331
1991	0.188	0.174	0.320
1992	0.266	0.210	0.321
1993	0.145	0.169	0.321
1994	0.433	0.204	
1995	0.170	0.185	

Furthermore, the actual and simulated outflow data is compared for each reservoir by using mean squared error to test the model accuracy. Table 16 shows the results for each reservoir. According to the table, the results indicate that the deviation of the actual data and simulated data is not larger.

Table 18. Comparison of actual and simulated outflow by using mean squared error for each reservoir

Reservoirs	Mean Squarred Error (%)
Cannonsville	2
Pepacton	7
Neversink	6

5. DISCUSSION

The Delaware River Basin has been home to contentious debates over water allocation and management in the Eastern United States. The four states in the basin, New York, Pennsylvania, New Jersey and Delaware, have been negotiating on water allocation agreements since the early years of the republic. Extensive hydrological modeling approaches have proceeded from the negotiations. The model described in this study included the development of the NYC reservoirs model, which predicts reservoir releases based on inflows to reservoirs, water demand by sector and historical reservoir management policies. The impact of this study extends directly to decision makers and stakeholders who rely on water resources in the Delaware River Basin.

The STELLA model is developed for NYC reservoirs operation is to better understand cumulative effects of water withdrawals on water resources and reservoir operations under different climatic conditions. Moreover, running the simulation over the period of fifteen years record and analyzing the main droughts in the basin shows how the different operations manage drought over the historical record. These simulations will help to compare the various operations for future scenarios.

Through the use of non-parametric statistical technique, the difference between actual daily storage data for each reservoir and the long-term median were compared. The analysis shows that there are no differences between datasets. Therefore, the seasonal operation zone approach is accepted to use in the model. With this approach, the available storage is determined in each reservoir for downstream purposes and recreational use of the reservoirs. Furthermore, the mean squared error is estimated to compare simulated and actual outflow data for each reservoir. The results show that the error between the actual and simulated data is not large. In other words, the model predicts the outflow of each reservoir close to the actual outflow data.

There are also some limitations in this study. The STELLA model produces a message warning of a circular connection of the simulated outflow and water use sectors such as fish and lower basin demand sectors. Therefore, an actual/observed data is used to calculate water demand for fish and lower basin.

This study is an ongoing research. The current reservoir operation techniques will be implemented into the model, and then it will be run under future climate projections to asses how changes affects the water resources.

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Appendix A Historical Reservoir Operation Rules

This appendix presents all model equations established in the STELLA.

A.1. Main Model Code

Top-Level Model:

Cannonsville(t) = Cannonsville(t - dt) + (Inflow_Can - From_Can_to_D - WS_to_NYC_From_Can) * dt

INIT Cannonsville = 26966*0.133681e6

INFLOWS:

Inflow_Can = (Total_Inflow_Can*3600*24) + Precipitation_Can

OUTFLOWS:

From_Can_to_D = Spill_Can + Release_Can

WS_to_NYC_From_Can = mg_to_cf*Diversion_to_NYC_from_Can

Neversink(t) = Neversink(t - dt) + (Inflow_N - From_N_to_D - WS_to_NYC_From_N) * dt

INIT Neversink = 3750*0.133681e6

INFLOWS:

Inflow_N = (Total_Inflow_N*3600*24)+Precipitation_N

OUTFLOWS:

From_N_to_D = Spill_N+Release_N

WS_to_NYC_From_N = mg_to_cf*Diversion_to_NYC_from_N

Pepacton(t) = Pepacton(t - dt) + (Inflow_P - From_P_to_D - WS_to_NYC_From_P) * dt

INIT Pepacton = 54005*133680.556

INFLOWS:

Inflow_P = (Streamflow_P*3600*24)+Precipitation_P

OUTFLOWS:

From_P_to_D = Release_P+Spill_P

WS_to_NYC_From_P = Diversion_to_NYC_from_P*mgd_to_cfs*86400

A.2. Precipitation Code

Precipitation_Can = Area_Can*Rain_Can*ci_to_cf

Precipitation_N = Area_N*Rain_N*ci_to_cf

Precipitation_P = Area_P*Rain_Can*ci_to_cf

A.3. Drought Warning Line (Conversation to cubic foot)

Drought_Warning_cf_Rev1 = Drought_Warning_bg_Rev1*bg_to_cf

Drought_Warning_Rev4_cf = Drought_Warning_Rev_4_bg*bg_to_cf

A.4. Release Code

Release_Can = IF Inflow_Can+Cannonsville>=Demand_Can THEN Demand_Can ELSE Inflow_Can+Cannonsville

Release_N = IF Inflow_N+Neversink>=Demand_N THEN Demand_N ELSE Inflow_N+Neversink

Release_P = IF Inflow_P+Pepacton>=Demand_P THEN Demand_P ELSE Inflow_P+Pepacton

A.5. Thermal Release Code

Thermal_Release_from_C = IF Day_of_Year>120 AND Day_of_Year<=304 AND Temp_Hale_Eddy>=75 AND Total_Cum_Thermal_Rel<6000*86400 AND Combined_Storage>Drought_Warning_bg_Rev1*1000 THEN Observed_Can_Release_cf-Conservation_Release_Can-Montague_Release_from_C

ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND TIME>1353 AND TIME<=1398 AND Total_Cum_Thermal_Rel<=9000*86400 AND Temp_Hale_Eddy>=75 AND Combined_Storage>(Drought_Warning_bg_Rev1+60)*1000 THEN Observed_Can_Release_cf-Conservation_Release_Can-Montague_Release_from_C ELSE IF TIME>1696 AND TIME<=1766 AND Total_Cum_Thermal_Rel<=3500*86400 THEN Observed_Can_Release_cf-Conservation_Release_Can-Montague_Release_from_C ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=9000*86400 AND TIME>=2438 AND TIME<=2494 THEN Observed_Can_Release_cf-Conservation_Release_Can-Montague_Release_from_C ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=8000*86400 AND TIME>=3436 AND TIME<3589 THEN Observed_Can_Release_cf-Conservation_Release_Can-Montague_Release_from_C ELSE IF TIME>7788 AND TIME<8138 AND Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=half_of_excess_to_fishery_rev4 AND Temp_Hale_Eddy>=75 THEN Observed_Can_Release_cf-Montague_Release_from_C-Conservation_Release_Can ELSE IF TIME>8545 AND Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=TRB_REV7 AND Temp_Hale_Eddy>=75 THEN Observed_Can_Release_cf-Montague_Release_from_C-Conservation_Release_Can ELSE 0

Thermal_Release_From_N = IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=6000*86400 AND

Combined_Storage>Drought_Warning_bg_Rev1*1000 AND Temp_Bridgeville>=75 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND TIME>1353 AND TIME<=1398 AND Total_Cum_Thermal_Rel<=9000*86400 AND Temp_Bridgeville>=75 AND Combined_Storage>(Drought_Warning_bg_Rev1+60)*1000 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE IF TIME>1696 AND TIME<=1766 AND Total_Cum_Thermal_Rel<=3500*86400 AND Temp_Bridgeville>=75 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=9000*86400 AND TIME>=2438 AND TIME<=2494 AND Temp_Bridgeville>=75 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=8000*86400 AND TIME>=3436 AND TIME<3589 AND Temp_Bridgeville>=75 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE IF TIME>7788 AND TIME<8138 AND Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=half_of_excess_to_fishery_rev4 AND Temp_Bridgeville>=75 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE IF TIME>8545 AND Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=TRB_REV7 AND Temp_Bridgeville>=75 THEN Observed_N_Release_cf-Montague_N-Conservation_Release_N ELSE 0

Thermal_Release_from_P = IF Day_of_Year>120 AND Day_of_Year<=304 AND Temperature_Fish_E>=75 AND Total_Cum_Thermal_Rel<=6000*86400 AND Combined_Storage>Drought_Warning_bg_Rev1*1000 THEN Observed_Pep_Release_cf-Conservation_Release_P-Montague_Release_from_P ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND TIME>1353 AND TIME<=1398 AND Total_Cum_Thermal_Rel<=9000*86400 AND Temperature_Fish_E>=75 AND Combined_Storage>(Drought_Warning_bg_Rev1+60)*1000 THEN Observed_Pep_Release_cf-Conservation_Release_P-Montague_Release_from_P ELSE IF TIME>1696 AND TIME<=1766 AND Total_Cum_Thermal_Rel<=3500*86400 THEN Observed_Pep_Release_cf-Conservation_Release_P-Montague_Release_from_P ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=9000*86400 AND TIME>=2438 AND TIME<=2494 THEN Observed_Pep_Release_cf-Conservation_Release_P-Montague_Release_from_P ELSE IF Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=8000*86400 AND TIME>=3436 AND TIME<3589 THEN Observed_Pep_Release_cf-Conservation_Release_P-Montague_Release_from_P ELSE IF TIME>7788 AND TIME<8138 AND Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=half_of_excess_to_fishery_rev4 AND Temperature_Fish_E>=75 THEN Observed_Pep_Release_cf-Montague_Release_from_P-Conservation_Release_P ELSE IF TIME>8545 AND Day_of_Year>120 AND Day_of_Year<=304 AND Total_Cum_Thermal_Rel<=TRB_REV7 AND Temperature_Fish_E>=75 THEN Observed_Pep_Release_cf-Montague_Release_from_P-Conservation_Release_P ELSE 0

Total_Thermal_Release_cf = Thermal_Release_From_N+Thermal_Release_from_C+Thermal_Release_from_P

A.6. Delaware Routing Code

To_Delaware = From_P_to_D+From_Can_to_D

To_Port_Jervis = From_N_to_D+To_Delaware

A.7. Reservoir's Area

Area_Can = ((95.706*3068*(6.273e+6))/1150)+((4.614e+9)*45.35)

Area_N = ((34.941*3068*(6.273e+6))/1440)+((4.614e+9)*9.54)

Area_P = ((140.190*3068*(6.273e+6))/1280)+((4.614e+9)*67.1)

A.8. Conservation Releases (Wildlife and Aesthetic Water Use) Code

Conservation_Release_Can = IF TIME>=0 AND TIME<5532 THEN Rev_1_C ELSE IF TIME>=5532 AND TIME<=6323 THEN Rev_3_C ELSE IF TIME>=6323 AND TIME<=6810 THEN Rev_4_C ELSE IF TIME>6810 AND TIME<=6874 THEN Additional_Releases_C ELSE IF TIME>6874 AND TIME<=7393 THEN Rev_4_C ELSE IF TIME>7393 AND TIME<=8151 THEN Rev_5_C ELSE Rev_7_withbank_C

Conservation_Release_N = IF TIME>=0 AND TIME<=4585 THEN Rev_1_N ELSE IF TIME>4585 AND TIME<=6800 THEN Rev_2_N ELSE IF TIME>6800 AND TIME<=8627 THEN Rev_4_N ELSE Rev_7_wbank_N

Conservation_Release_P = IF TIME>=0 AND TIME<=4585 THEN Rev_1_P ELSE IF TIME>4585 AND TIME<=6800 THEN Rev_2_P ELSE IF TIME>6800 AND TIME<=8627 THEN Rev_4_P ELSE Rev_7_wbank_P

A.9. Augmented and Basic Release Code

```
Augmented_Releases_C = IF Day_of_Year>0 AND Day_of_Year>90 THEN 33*86400
ELSE IF Day_of_Year>=166 AND Day_of_Year<=227 THEN 325*86400 ELSE IF
Day_of_Year>305 AND Day_of_Year<=365 THEN 33*86400 ELSE 45*86400

Augmented_Releases_C_Rev3 = IF Day_of_Year>=152 AND Day_of_Year<=227
THEN 160*86400 ELSE 45*86400

Augmented_Releases_N = IF Day_of_Year>=0 AND Day_of_Year>90 THEN 25*86400
ELSE IF Day_of_Year>305 AND Day_of_Year<=365 THEN 25*86400 ELSE
45*86400

Augmented_Releases_N_Rev2 = IF Day_of_Year>=121 AND Day_of_Year<=273
THEN 53*86400 ELSE 25*86400

Augmented_Releases_P = IF Day_of_Year>90 AND Day_of_Year<=304 THEN
70*86400 ELSE 50*86400

Augmented_Releases_P_Rev2 = IF Day_of_Year>120 AND Day_of_Year<=151 THEN
70*86400 ELSE IF Day_of_Year>152 AND Day_of_Year<=243 THEN 95*86400
ELSE IF Day_of_Year>244 AND Day_of_Year<=273 THEN 70*86400 ELSE
45*86400
```

Basic_Releases_C = IF Day_of_Year>=106 AND Day_of_Year<=315 THEN 23*86400 ELSE 8*86400

Basic_Releases_N = IF Day_of_Year>=98 AND Day_of_Year<=285 THEN 15*86400 ELSE 5*86400

Basic_Releases_P = IF Day_of_Year>97 AND Day_of_Year<=304 THEN 19*86400 ELSE 6*86400

A.10. Drought Emergency Conditions for Conservation Releases

D_Emer_Cond_N_rev1 = IF Combined_Storage<=Drought_Warning_bg_Rev1*1000 OR DELAY (Combined_Storage<=Drought_Warning_bg_Rev1*1000, 5) THEN Basic_Releases_N ELSE Augmented_Releases_N

D_Emer_Cond_rev1_C = IF Combined_Storage<=Drought_Warning_bg_Rev1*1000 OR DELAY (Combined_Storage<=Drought_Warning_bg_Rev1*1000, 5) THEN Basic_Releases_C ELSE Augmented_Releases_C

D_Emergency_Cond_C_rev4 = IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 OR DELAY (Combined_Storage<=Drought_Warning_Rev_4_bg*1000, 5) THEN Basic_Releases_C ELSE IF Combined_Storage>Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Normal_Storage_Level_bg*1000 THEN Augmented_Releases_C_Rev3 - (Augmented_Releases_C_Rev3*0.85) ELSE Augmented_Releases_C_Rev3

D_Emergency_rev3_C = IF Combined_Storage<=Drought_Warning_bg_Rev1*1000 OR DELAY (Combined_Storage<=Drought_Warning_bg_Rev1*1000, 5) THEN Basic_Releases_C ELSE Augmented_Releases_C_Rev3

Drought_Em_rev4_N = IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 OR DELAY (Combined_Storage<=Drought_Warning_Rev_4_bg*1000, 5) THEN Basic_Releases_N ELSE IF Combined_Storage>Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Normal_Storage_Level_bg*1000 THEN Augmented_Releases_N_Rev2-(0.85*Augmented_Releases_N_Rev2) ELSE Augmented_Releases_N_Rev2

Drought_Emergency_rev1 = IF Combined_Storage<=Drought_Warning_bg_Rev1*1000 OR DELAY (Combined_Storage<=Drought_Warning_bg_Rev1*1000, 5) THEN Basic_Releases_P ELSE Augmented_Releases_P

Drought_Emergency_rev2 = IF Combined_Storage<=Drought_Warning_bg_Rev1*1000 OR DELAY (Combined_Storage<=Drought_Warning_bg_Rev1*1000, 5) THEN Basic_Releases_P ELSE Augmented_Releases_P_Rev2

Drought_Emergency_rev2_N = IF Combined_Storage<=Drought_Warning_bg_Rev1*1000 OR DELAY (Combined_Storage<=Drought_Warning_bg_Rev1*1000, 5) THEN Basic_Releases_N ELSE Augmented_Releases_N_Rev2

Drought_Emergency_rev4 = IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 OR DELAY (Combined_Storage<=Drought_Warning_Rev_4_bg*1000, 5) THEN Basic_Releases_P ELSE IF Combined_Storage>Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Normal_Storage_Level_bg*1000 THEN Augmented_Releases_P_Rev2 - (0.85*Augmented_Releases_P_Rev2) ELSE Augmented_Releases_P_Rev2

A.11. Conservation Releases Normal Conditions Code

New_Jersey_Basin_Bank = IF TIME>1696 AND TIME<=1766 THEN Cum_Montague_saving*0.25 ELSE 0

Normal_C_rev7 = IF Day_of_Year>152 AND Day_of_Year<=243 THEN 60*86400 ELSE 45*86400

Normal_Cond_C_rev4 = IF Combined_Storage>Drought_Warning_Rev_4_bg*1000 OR DELAY(Combined_Storage>Drought_Warning_Rev_4_bg*1000+15000,15) THEN Augmented_Releases_C_Rev3 ELSE Basic_Releases_C

Normal_Cond_N_rev1 = IF Combined_Storage>Drought_Warning_bg_Rev1*1000 OR DELAY(Combined_Storage>Drought_Warning_bg_Rev1*1000+15000,15) THEN Augmented_Releases_N ELSE Basic_Releases_N

Normal_Cond_rev1_C = IF Combined_Storage>Drought_Warning_bg_Rev1*1000 OR DELAY(Combined_Storage>Drought_Warning_bg_Rev1*1000+15000,15) THEN Augmented_Releases_C ELSE Basic_Releases_C

Normal_cond_rev2 = IF Combined_Storage>Drought_Warning_bg_Rev1*1000 OR DELAY(Combined_Storage>Drought_Warning_bg_Rev1*1000+15000,15) THEN Augmented_Releases_P_Rev2 ELSE Basic_Releases_P

Normal_Cond_rev2_N = IF Combined_Storage>Drought_Warning_bg_Rev1*1000 OR DELAY(Combined_Storage>Drought_Warning_bg_Rev1*1000+15000,15) THEN Augmented_Releases_N_Rev2 ELSE Basic_Releases_N

Normal_Cond_rev3_C = IF Combined_Storage>Drought_Warning_bg_Rev1*1000 OR DELAY(Combined_Storage>Drought_Warning_bg_Rev1*1000+15000,15) THEN Augmented_Releases_C_Rev3 ELSE Basic_Releases_C

Normal_Cond_rev4 = IF Combined_Storage>Drought_Warning_Rev_4_bg*1000 OR DELAY(Combined_Storage>Drought_Warning_Rev_4_bg*1000+15000,15) THEN Augmented_Releases_P_Rev2 ELSE Basic_Releases_P

Normal_Conditions_rev1 = IF Combined_Storage>Drought_Warning_bg_Rev1*1000 OR DELAY(Combined_Storage>Drought_Warning_bg_Rev1*1000+15000,15) THEN Augmented_Releases_P ELSE Basic_Releases_P

normal_Crev7 = IF Day_of_Year>=152 AND Day_of_Year<=182 THEN 160*86400 ELSE 45*86400

Normal_Nrev7 = IF Day_of_Year>=120 AND Day_of_Year<=242 THEN 53*86400 ELSE 25*86400

Normal_Prev7 = IF Day_of_Year>120 AND Day_of_Year<=151 THEN 70*86400 ELSE IF Day_of_Year>152 AND Day_of_Year<=243 THEN 95*86400 ELSE IF Day_of_Year>244 AND Day_of_Year<=273 THEN 70*86400 ELSE 45*86400

Normal_Rel_rev4_N = IF Combined_Storage>Drought_Warning_Rev_4_bg*1000 OR DELAY(Combined_Storage>Drought_Warning_Rev_4_bg*1000+15000,15) THEN Augmented_Releases_N_Rev2 ELSE Basic_Releases_N

A.12. Drought Trigger Code for Conservation Releases

Rev_1_C = IF Combined_Storage>=Drought_Warning_bg_Rev1*1000 THEN Normal_Cond_rev1_C ELSE D_Emer_Cond_rev1_C

Rev_1_N = IF Combined_Storage>=Drought_Warning_bg_Rev1*1000 THEN Normal_Cond_N_rev1 ELSE D_Emer_Cond_N_rev1

Rev_1_P = IF Combined_Storage>=Drought_Warning_bg_Rev1*1000 THEN Normal_Conditions_rev1 ELSE Drought_Emergency_rev1

Rev_2_N = IF Combined_Storage>=Drought_Warning_bg_Rev1*1000 THEN Normal_Cond_rev2_N ELSE Drought_Emergency_rev2_N

Rev_2_P = IF Combined_Storage>=Drought_Warning_bg_Rev1*1000 THEN Normal_cond_rev2 ELSE Drought_Emergency_rev2

Rev_3_C = IF Combined_Storage>=Drought_Warning_bg_Rev1*1000 THEN Normal_Cond_rev3_C ELSE D_Emergency_rev3_C

Rev_4_C = IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 THEN Normal_Cond_C_rev4 ELSE D_Emergency_Cond_C_rev4

Rev_4_N = IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 THEN Normal_Rel_rev4_N ELSE Drought_Em_rev4_N

Rev_4_P = IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 THEN Normal_Cond_rev4 ELSE Drought_Emergency_rev4

Rev_5_C = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN 45*86400 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN 35*86400 ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 THEN 23*86400 ELSE IF Combined_Storage<=Drought_bg*1000 THEN Basic_Releases_C ELSE 0

Rev_7_N_Conservation_release = IF TIME>8545 THEN Rev_7_wbank_N+in_case_of_low_usable_capacity_of_reservoir ELSE Rev_7_wbank_N

Rev_7_wbank_N = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN 25*86400 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN 21*86400 ELSE IF

Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 THEN 18*86400 ELSE IF Combined_Storage<=Drought_bg*1000 THEN 15*86400 ELSE IF remaining_habitat_bank<=0 THEN Ref_Rel_N ELSE 0

Rev_7_wbank_P = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN 35*86400 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN 30*86400 ELSE IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Drought_bg*1000 THEN 25*86400 ELSE IF Combined_Storage<=Drought_bg*1000 THEN 19*86400 ELSE IF remaining_habitat_bank<=0 THEN Reference_Rel_P ELSE 0

Rev_7_withbank_C = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN Normal_C_rev7 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN Drought_Watch_C_rev7 ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 THEN Drought_Warning_C_rev7 ELSE IF Combined_Storage<=Drought_bg*1000 THEN 23*86400 ELSE IF remaining_habitat_bank<=0 THEN Ref_Rel_Can ELSE 0

A.13. Additional Release from Cannonsville

Additional_Releases_C = IF Day_of_Year>=240 AND Day_of_Year<=258 AND (Hale_Eddy_Flow*86400)<(200*86400) AND Total_Cum_Thermal_Rel<=(6000*86400) THEN (40+160)*86400 ELSE IF Day_of_Year>=259 AND Day_of_Year<=304 AND

(Hale_Eddy_Flow*86400)<(200*86400) AND Total_Cum_Thermal_Rel<=(6000*86400) THEN (115+45)*86400 ELSE Rev_4_C

A.14. Conservation Releases for Habitat Bank (Revision 7)

D_Watch_Crev7 = IF Day_of_Year>=152 AND Day_of_Year<=182 THEN 136*86400 ELSE 38*86400

D_Watch_Nrev7 = IF Day_of_Year>=120 AND Day_of_Year<=242 THEN 45*86400 ELSE 21*86400

D_Watch_P_rev7 = IF Day_of_Year>120 AND Day_of_Year<=151 THEN 60*86400 ELSE IF Day_of_Year>152 AND Day_of_Year<=243 THEN 81*86400 ELSE IF Day_of_Year>244 AND Day_of_Year<=273 THEN 60*86400 ELSE 38*86400

Drought_Warning_C_rev7 = IF Day_of_Year>152 AND Day_of_Year<=243 THEN 43*86400 ELSE 32*86400

Drought_Watch_C_rev7 = IF Day_of_Year>152 AND Day_of_Year<=243 THEN 51*86400 ELSE 38*86400

A.15. Drought Emergency Code in 1985

Montague_saving = IF Montague_Min_Release_Rev_1=Drought_Warning_1985 THEN (1550*86400)-Drought_Warning_1985 ELSE 0

Thermal_Em_Rel_1985 = IF Thermal_Release_from_P+Thermal_Release_from_C+Thermal_Release_From_N<=Thermal_Emergency_Bank_1985 AND TIME>1696 AND TIME<=1766 THEN 1 ELSE 0

Thermal_Emergency_Bank_1985 = IF TIME>1696 AND TIME<=1766 THEN Cum_Montague_saving*0.25 ELSE 0

Basin_Bank = IF TIME>1696 AND TIME<=1766 THEN Cum_Montague_saving*0.5 ELSE 0

Drought_Warning_1985 = IF Day_of_Year> 0 AND Day_of_Year<=120 AND Reedy_Island_RM_54>=250 THEN 1300*86400 ELSE IF Day_of_Year> 0 AND Day_of_Year<=120 AND Chester_RM_83>=250 AND Forth_Miffin_RM_91>=250 THEN 1600*86400 ELSE IF Day_of_Year> 0 AND Day_of_Year<=120 AND B_Franklin_RM_100>=250 THEN 1650*86400 ELSE IF Day_of_Year>120 AND Day_of_Year<=243 AND Reedy_Island_RM_54>=250 THEN 1350*86400 ELSE IF Day_of_Year>120 AND Day_of_Year<=243 AND Chester_RM_83>=250 AND Forth_Miffin_RM_91>=250 THEN 1350*86400 ELSE IF Day_of_Year>120 AND Day_of_Year<=243 AND B_Franklin_RM_100>=250 THEN 1600*86400 ELSE IF Day_of_Year>243 AND Day_of_Year<=334 AND Reedy_Island_RM_54>=250 THEN 1300*86400 ELSE IF Day_of_Year> 243 AND Day_of_Year<=334 AND Chester_RM_83>=250 AND Forth_Miffin_RM_91>=250 THEN 1500*86400 ELSE IF Day_of_Year> 243 AND Day_of_Year<=334 AND B_Franklin_RM_100>=250 THEN 1650*86400 ELSE 0

A.16. Reservoir Capacities

Capacity_Can = 95706

Capacity_N = 34941

Capacity_P = 140190

Total_Capacity = Capacity_Can+Capacity_P+Capacity_N

A.11. Chloride Concentration Calculations

```
Chester_RM_83 = (((0.36996)/(((Chester_Cond*0.001)^(-1.07))-(0.7464*10^-3)))*((1.3855+(-0.046485668*Chester_Temp)+(0.001488779*Chester_Temp^2)+(-6.30834E-05*Chester_Temp^3)+(2.51445E-06*Chester_Temp^4)+(-5.96002E-08*Chester_Temp^5)+(5.77781E-10*Chester_Temp^6))))*1000
ci_to_cf = 0.000578704

Reedy_Island_RM_54 = (((0.36996)/(((Reedy_Island_Conductance*0.001)^(-1.07))-(0.7464*10^-3)))*((1.3855+(-0.046485668*Reedy_Island_Temp)+(0.001488779*Reedy_Island_Temp^2)+(-6.30834E-05*Reedy_Island_Temp^3)+(2.51445E-06*Reedy_Island_Temp^4)+(-5.96002E-08*Reedy_Island_Temp^5)+(5.77781E-10*Reedy_Island_Temp^6))))*1000
```

A.17. Combined Storage Code

```
Combined_Storage = Storage_C+Storage_P+Storage_N
```

A.18. Habitat Bank Code

```
TRB_REV7 = IF Combined_Storage>Normal_Storage_Level_bg*1000 AND Combined_Storage<Drought_Warning_Rev_4_bg*1000 THEN (9200*86400)*0.85 ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 THEN (9200*86400)*0.85 ELSE IF Combined_Storage<=Drought_bg*1000 THEN 0 ELSE 9200*86400

Credit_to_HBR = Cum_Habitat_Bank_Rel-Rev_5_C
Credit_to_HBR_positive = IF Credit_to_HBR<0 THEN 0 ELSE Credit_to_HBR
```

Total_habitat_bank_rev7 = Habitat_Rel_Bank_rev7_N+Habitat_Release_Bank_rev7_P+Habitat_Rel_Bank_rev7_Ca n

A.19. Day of the Year Code

Day_of_Year = IF (TIME MOD 365)=0 THEN 365 ELSE (TIME MOD 365)

A.20. Basin Demand Code

Demand_Can = IF TIME>=0 AND TIME<=1126 THEN Thermal_and_Conservation_Rel_C+Montague_Release_from_C ELSE Conservation_Release_Can+Thermal_Release_from_C+Montague_Release_from_C

Demand_N = IF TIME>=0 AND TIME<=1126 THEN Thermal_and_Conservation_Rel_N+Montague_N ELSE Conservation_Release_N+Thermal_Release_From_N+Montague_N

Demand_P = IF TIME>=0 AND TIME<=1126 THEN Thermal_and_Conservation_Rel_P+Montague_Release_from_P ELSE Conservation_Release_P+Thermal_Release_from_P+Montague_Release_from_P

Drought_cf = Drought_bg*bg_to_cf

A.21. Excess Release Bank for Habitat Bank (Rev 7) Code

ERB_REV7 = 5700*86400

A.22. Excess Release Bank Code

Excess_Release_cf = IF TIME>=0 AND TIME<6800 AND Cum_excess_release_rev1<=70*bg_to_cf THEN Excess_Release_Rev_1 ELSE IF Cum_excess_release_rev4<=70*bg_to_cf AND TIME>=6800 AND TIME<=9131 THEN Excess_release_rev4 ELSE 0

Excess_Release_Rev_1 = IF Day_of_Year>=166 AND Day_of_Year<=333 OR Day_of_Year>0 AND Day_of_Year<=74 AND Montague_Observed_Flow_cf<= 1850*86400 AND Combined_Storage>Drought_Warning_bg_Rev1*1000 THEN Montague_Observed_Flow_cf-Montague_Excess_Design_cf ELSE 0

Excess_release_rev4 = IF Day_of_Year>0 AND Day_of_Year<=74 OR Day_of_Year>=166 AND Day_of_Year<=365 AND Montague_Observed_Flow_cf<=1850*86400 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN Montague_Observed_Flow_cf-Montague_Excess_Design_cf ELSE 0

half_of_excess_to_fishery_rev4 = IF TIME>6718 AND TIME<7788 THEN Total_Cum_Excess_Rel*0.5 ELSE 0

half_of_excess_to_Montague_rev4 = IF TIME>6718 AND TIME<7788 THEN Total_Cum_Excess_Rel*0.5 ELSE 0

Safe_Yield = 607.725

Total_Excess_Release = IF TIME>=2022 AND TIME<=2294 THEN (8418*86400)/bg_to_cf ELSE IF TIME>3536 AND TIME<3589 THEN (9418*86400)/bg_to_cf ELSE (Safe_Yield-NYC_Demand)*0.83

remaining_from_thermal_to_ERB = Total_Thermal_Release_cf-half_of_excess_to_fishery_rev4

A.23. Habitat Bank Release Code

Habitat_Bank_Rel_Can_rev5_and6 = IF Hale_Eddy_Flow<225*86400 AND Combined_Storage*mg_to_cf>Normal_Storage_cf AND Cum_Habitat_Bank_Rel<=Habitat_Bank_rev5_and_6 THEN Observed_Can_Release_cf-Thermal_Release_from_C-Montague_C-Conservation_Release_Can ELSE IF Hale_Eddy_Flow<190*86400 AND Combined_Storage*mg_to_cf<=Normal_Storage_cf AND Combined_Storage*mg_to_cf>Drought_Warning_Rev4_cf AND Cum_Habitat_Bank_Rel<=Habitat_Bank_rev5_and_6 THEN Observed_Can_Release_cf-Thermal_Release_from_C-Montague_C-Conservation_Release_Can ELSE IF Hale_Eddy_Flow<150*86400 AND Combined_Storage*mg_to_cf<=Drought_Warning_Rev4_cf AND Combined_Storage*mg_to_cf>Drought_cf AND Cum_Habitat_Bank_Rel<=Habitat_Bank_rev5_and_6 THEN Observed_Can_Release_cf-Thermal_Release_from_C-Montague_C-Conservation_Release_Can ELSE IF Combined_Storage*mg_to_cf<Drought_cf THEN 0 ELSE 0

Habitat_Bank_rev5_and_6 = IF TIME> 7788 AND TIME< 8545 THEN remaining_from_thermal_to_ERB+Credit_to_HBR_positive ELSE 0

Habitat_bank_rev7 = IF TIME> 8545 THEN TRB_REV7+SRB+ERB_REV7+Credit_to_HBR_positive+Remaining_TRB ELSE 0

remaining_habitat_bank = Habitat_bank_rev7-Cum_Habitat_Bank_Rel

Remaining_TRB = TRB_REV7-Total_Cum_Thermal_Rel

Habitat_Rel_Bank_rev7_Can = IF Combined_Storage>Normal_Storage_Level_bg*1000 AND Hale_eddy_cf<225*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_Can_Release_cf-Conservation_Release_Can-Thermal_Release_from_C-Montague_Release_from_C ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 AND Hale_eddy_cf<190*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_Can_Release_cf-Conservation_Release_Can-Thermal_Release_from_C-Montague_Release_from_C ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 AND Hale_eddy_cf<160*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_Can_Release_cf-Conservation_Release_Can-Thermal_Release_from_C-Montague_Release_from_C ELSE IF Combined_Storage<=Drought_bg*1000 AND Hale_eddy_cf<145*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_Can_Release_cf-

Conservation_Release_Can-Thermal_Release_from_C-Montague_Release_from_C ELSE IF Combined_Storage<67.7*1000 THEN 0 ELSE 0

Habitat_Rel_Bank_rev7_N = IF Combined_Storage>Normal_Storage_Level_bg*1000 AND Bridgeville_cf<115*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_N_Release_cf-Conservation_Release_N-Thermal_Release_From_N-Montague_N ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 AND Bridgeville_cf<100*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_N_Release_cf-Conservation_Release_N-Thermal_Release_From_N-Montague_N ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 AND Bridgeville_cf<80*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_N_Release_cf-Conservation_Release_N-Thermal_Release_From_N-Montague_N ELSE IF Combined_Storage<=Drought_bg*1000 AND Bridgeville_cf<75*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN Observed_N_Release_cf-Conservation_Release_N-Thermal_Release_From_N-Montague_N ELSE IF Combined_Storage<67.7*1000 THEN 0 ELSE 0

Habitat_Release_Bank_rev7_P = IF Combined_Storage>Normal_Storage_Level_bg*1000 AND Harvard_cf<175*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN From_P_to_D-Conservation_Release_P-Thermal_Release_from_P-Montague_Release_from_P ELSE

IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 AND Harvard_cf<150*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN From_P_to_D-Conservation_Release_P-Thermal_Release_from_P-Montague_Release_from_P ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 AND Harvard_cf<120*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN From_P_to_D-Conservation_Release_P-Thermal_Release_from_P-Montague_Release_from_P ELSE IF Combined_Storage<=Drought_bg*1000 AND Harvard_cf<115*86400 AND Cum_Habitat_Bank_Rel<=Habitat_bank_rev7 THEN From_P_to_D-Conservation_Release_P-Thermal_Release_from_P-Montague_Release_from_P ELSE IF Combined_Storage<67.7*1000 THEN 0 ELSE 0

Hale_eddy_cf = Hale_Eddy_Flow*86400

A.24. Montague Target River Master Code

Montague_1981 = IF TIME>0 AND TIME<=31 THEN 1550*86400 ELSE IF TIME>31 AND TIME<=48 THEN 1550*86400 ELSE IF TIME>=49 AND TIME<=84 THEN 1350*86400 ELSE IF TIME>=85 AND TIME<=168 THEN 1100*86400 ELSE IF TIME>=386 AND TIME<=385 THEN 1560*86400 ELSE IF TIME>=387 AND TIME<396 THEN 1550*86400 ELSE 1750*86400

Montague_1982 = IF TIME>=396 AND TIME<=513 THEN 0 ELSE IF TIME>=513 AND TIME<=561 THEN 1750*86400 ELSE IF TIME>=562 AND TIME<=712 THEN 1850*86400 ELSE IF TIME>=713 AND TIME<=729 THEN 1655*86400 ELSE IF

TIME>=730 AND TIME<=754 THEN 1750*86400 ELSE IF TIME>=755 AND TIME<=761 THEN 1700*86400 ELSE 0

Montague_1983 = IF TIME>761 AND TIME<847 THEN 1550*86400 ELSE IF TIME>=927 AND TIME<=1026 THEN 1850*86400 ELSE IF TIME>=1074 AND TIME<=1095 THEN 1665*86400 ELSE IF TIME>=1096 AND TIME<=1103 THEN 1655*86400 ELSE IF TIME>=1104 AND TIME<=1126 THEN 1550*86400 ELSE 1750*86400

A.25. Montague Demand (Lower Basin Demand) Code

Montague_C = IF TIME>=0 AND TIME<=1126 THEN Montague_River_Master_Can ELSE Montague_IWRM_Can

Montague_Design_Rate_During_Excess_Release_Period = 1750+((Total_Excess_Release*1547)/120)

Montague_Drought_cf = IF Combined_Storage<=Drought_bg*1000 THEN Montague_Releases_under_drought ELSE 0

Montague_Excess_Design_cf = Montague_Design_Rate_During_Excess_Release_Period*86400

Montague_IWRM_Can = IF Power_releases_delayed_1day+Uncontrolled_Releases_cf+DELAY (Conservation_Release_Can, 3)+Observed_N_delayed_3_days+Observed_P_delayed_3_days<=Montague_Min_Release_cf+Excess_Release_cf THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-Observed_Pep_Release_cf-

Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_Can-Thermal_Rel_Sim_C ELSE 0

Montague_IWRM_N = IF Power_releases_delayed_1day+Uncontrolled_Releases_cf+DELAY (Conservation_Release_N, 3)+Observed_can_delayed_3_days+Observed_P_delayed_3_days<=Montague_Min_Release_cf+Excess_Release_cf THEN Montague_Observed_after_3_days-DELAY (Observed_Can_Release_cf, 1)-Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_N-Thermal_Rel_Sim_N ELSE 0

Montague_IWRM_P = IF Power_releases_delayed_1day+Uncontrolled_Releases_cf+DELAY (Conservation_Release_P, 3)+Observed_N_delayed_3_days+Observed_can_delayed_3_days<=Montague_Min_Release_cf+Excess_Release_cf THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-DELAY(Observed_Can_Release_cf, 1)-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_P-Thermal_Release_Sim_P ELSE 0

Montague_Min_Release_cf = IF TIME>=0 AND TIME<6800 THEN Montague_Min_Release_Rev_1 ELSE Montague_Min_Release_Rev_4

Montague_Min_Release_Rev_1 = IF Combined_Storage>=Normal_Storage_Level_bg*1000 THEN 1750*86400 ELSE IF

Combined_Storage<Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_bg_Rev1*1000 THEN 1665*86400 ELSE IF Combined_Storage<Drought_Warning_bg_Rev1*1000 AND Combined_Storage>Drought_bg*1000 THEN 1550*86400 ELSE IF TIME>1696 AND TIME<=1766 AND Combined_Storage<Drought_Warning_bg_Rev1*1000 AND Combined_Storage>Drought_bg*1000 THEN Drought_Warning_1985 ELSE Montague_Drought_cf

Montague_Min_Release_Rev_4 = IF Combined_Storage>=Normal_Storage_Level_bg*1000 THEN 1750*86400 ELSE IF Combined_Storage<Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN 1665*86400 ELSE IF Combined_Storage<Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 THEN 1550*86400 ELSE Montague_Drought_cf

Montague_N = IF Montague_Rel_from_N<0 THEN 0 ELSE Montague_Rel_from_N

Montague_P = IF TIME>=0 AND TIME<=1126 THEN Montague_River_Master_P ELSE Montague_IWRM_P

Montague_Rel_from_N = IF TIME>=0 AND TIME<=1126 THEN Montague_River_Master_N ELSE Montague_IWRM_N

Montague_Release_from_C = IF Montague_C<0 THEN 0 ELSE Montague_C

Montague_Release_from_P = IF Montague_P<0 THEN 0 ELSE Montague_P

Montague_Releases_under_drought = IF Day_of_Year> 0 AND Day_of_Year<=120 AND Reedy_Island_RM_54>=250 THEN 1100*86400 ELSE IF Day_of_Year> 0 AND Day_of_Year<=120 AND Chester_RM_83>=250 AND Forth_Miffin_RM_91>=250 THEN 1600*86400 ELSE IF Day_of_Year> 0 AND Day_of_Year<=120 AND B_Franklin_RM_100>=250 THEN 1650*86400 ELSE IF Day_of_Year>120 AND Day_of_Year<=243 AND Reedy_Island_RM_54>=250 THEN 1100*86400 ELSE IF Day_of_Year>120 AND Day_of_Year<=243 AND Chester_RM_83>=250 AND Forth_Miffin_RM_91>=250 THEN 1350*86400 ELSE IF Day_of_Year>120 AND Day_of_Year<=243 AND B_Franklin_RM_100>=250 THEN 1600*86400 ELSE IF Day_of_Year>243 AND Day_of_Year<=334 AND Reedy_Island_RM_54>=250 THEN 1100*86400 ELSE IF Day_of_Year> 243 AND Day_of_Year<=334 AND Chester_RM_83>=250 AND Forth_Miffin_RM_91>=250 THEN 1500*86400 ELSE IF Day_of_Year> 243 AND Day_of_Year<=334 AND B_Franklin_RM_100>=250 THEN 1650*86400 ELSE 0

Montague_River_Master_Can = IF TIME>0 AND TIME<396 AND Power_releases_delayed_1day+Uncontrolled_Releases_cf+DELAY (Conservation_Release_Can, 3)+Observed_N_delayed_3_days+Observed_P_delayed_3_days<=Montague_1981 THEN Montague_Observed_after_3_days-DELAY (Observed_N_Release_cf, 1)-Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-

Power_Releases_delayed_3_days-Conservation_Release_Can-Thermal_Rel_Sim_C ELSE IF TIME>=396 AND TIME<=761 AND Uncontrolled_Releases_cf+Power_releases_delayed_1day+DELAY (Conservation_Release_Can, 3)+Observed_N_delayed_3_days+Observed_P_delayed_3_days<=Montague_1982+Excess_Release_cf THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_Can-Thermal_Rel_Sim_C ELSE IF TIME>761 AND TIME<=1126 AND Power_releases_delayed_1day+Uncontrolled_Releases_after_3_days+DELAY (Conservation_Release_Can, 3)+Observed_N_delayed_3_days+Observed_P_delayed_3_days<=Montague_1983 THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_Can-Thermal_Rel_Sim_C ELSE 0

Montague_River_Master_N = IF TIME>0 AND TIME<396 AND Power_releases_delayed_1day+Uncontrolled_Releases_cf+DELAY (Conservation_Release_N, 3)+Observed_can_delayed_3_days+Observed_P_delayed_3_days<=Montague_1981 THEN Montague_Observed_after_3_days-DELAY (Observed_Can_Release_cf, 1)-

Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_N-Thermal_Rel_Sim_N ELSE IF TIME>=396 AND TIME<=761 AND Uncontrolled_Releases_cf+Power_releases_delayed_1day+DELAY (Conservation_Release_N, 3)+Observed_can_delayed_3_days+Observed_P_delayed_3_days<=Montague_1982+Excess_Release_cf THEN Montague_Observed_after_3_days-DELAY(Observed_Can_Release_cf, 1)-Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_N-Thermal_Rel_Sim_N ELSE IF TIME>761 AND TIME<=1126 AND Power_releases_delayed_1day+Uncontrolled_Releases_after_3_days+DELAY (Conservation_Release_N, 3)+Observed_can_delayed_3_days+Observed_P_delayed_3_days<=Montague_1983 THEN Montague_Observed_after_3_days-DELAY(Observed_Can_Release_cf, 1)-Observed_Pep_Release_cf-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_N-Thermal_Rel_Sim_N ELSE 0

Montague_River_Master_P = IF TIME>0 AND TIME<396 AND Power_releases_delayed_1day+Uncontrolled_Releases_cf+DELAY (Conservation_Release_P, 3)+Observed_N_delayed_3_days+Observed_can_delayed_3_days<=Montague_1981 THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-

DELAY(Observed_Can_Release_cf, 1)-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_P-Thermal_Release_Sim_P ELSE IF TIME>=396 AND TIME<=761 AND Uncontrolled_Releases_cf+Power_releases_delayed_1day+DELAY (Conservation_Release_P, 3)+Observed_N_delayed_3_days+Observed_can_delayed_3_days<=Montague_1982+Excess_Release_cf THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-DELAY(Observed_Can_Release_cf, 1)-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_P-Thermal_Release_Sim_P ELSE IF TIME>761 AND TIME<=1126 AND Power_releases_delayed_1day+Uncontrolled_Releases_after_3_days+DELAY (Conservation_Release_P, 3)+Observed_N_delayed_3_days+Observed_can_delayed_3_days<=Montague_1983 THEN Montague_Observed_after_3_days-DELAY(Observed_N_Release_cf, 1)-DELAY(Observed_Can_Release_cf, 1)-Uncontrolled_Releases_after_3_days-Power_Releases_delayed_3_days-Conservation_Release_P-Thermal_Release_Sim_P ELSE 0

A.26. Power Reservoir Releases

Observed_W_delayed_3days_cf = Observed_W_delayed*86400

Power_releases_delayed_1day = Rio_obs_delayed_1day_cf+W_obs_delayed_1day_cf

Power_Releases_delayed_3_days = Observed_W_delayed_3days_cf+Observed_Rio_delayed_3days_cf

A.27. References Releases (Revision 7) Code

Ref_Rel_Can = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN normal_Crev7 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN D_Watch_Crev7 ELSE IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Drought_bg*1000 THEN Basic_Releases_C ELSE IF Combined_Storage<=Drought_bg*1000 THEN Basic_Releases_C ELSE 0

Ref_Rel_N = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN Normal_Nrev7 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN D_Watch_Nrev7 ELSE IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Drought_bg*1000 THEN Basic_Releases_N ELSE IF Combined_Storage<=Drought_bg*1000 THEN Basic_Releases_N ELSE 0

Reference_Rel_P = IF Combined_Storage>Normal_Storage_Level_bg*1000 THEN Normal_Prev7 ELSE IF Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN D_Watch_P_rev7 ELSE IF Combined_Storage>=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage<Drought_bg*1000 THEN Basic_Releases_P ELSE IF Combined_Storage<=Drought_bg*1000 THEN Basic_Releases_P ELSE 0

A.28. Spill Code

Spill_Can = IF Inflow_Can+Cannonsville-Demand_Can-WS_to_NYC_From_Can>=Rule_Curve_Can*mg_to_cf THEN Inflow_Can+Cannonsville-Demand_Can-(Rule_Curve_Can*mg_to_cf)-WS_to_NYC_From_Can ELSE 0

Spill_N = IF Inflow_N+Neversink-Demand_N-WS_to_NYC_From_N>=Rule_Curve_N*mg_to_cf THEN Inflow_N+Neversink-Demand_N-(Rule_Curve_N*mg_to_cf)-WS_to_NYC_From_N ELSE 0

Spill_P = IF Inflow_P+Pepacton-Demand_P-WS_to_NYC_From_P>=Rule_Curve_P*mg_to_cf THEN Inflow_P+Pepacton-Demand_P-(Rule_Curve_P*mg_to_cf)-WS_to_NYC_From_P ELSE 0

A.29. Supplemental Release Bank (Rev 7)

SRB = IF Combined_Storage>Normal_Storage_Level_bg*1000 AND Combined_Storage<Drought_Warning_Rev_4_bg*1000 THEN (5100*86400)*0.85 ELSE IF Combined_Storage<=Drought_Warning_Rev_4_bg*1000 AND Combined_Storage>Drought_bg*1000 THEN (5100*86400)*0.85 ELSE IF Combined_Storage<=Drought_bg*1000 THEN 0 ELSE 5100*86400

A.30. Thermal and Conservation Releases

Thermal_and_Conservation_Rel_C = IF Total_Withdrawal_from_ERB=Total_Conservation_Release_cf+Total_Thermal_Release_cf THEN Conservation_Release_Can+Thermal_Release_from_C ELSE 0

Thermal_and_Conservation_Rel_N = IF Total_Withdrawal_from_ERB=Total_Conservation_Release_cf+Total_Thermal_Release_cf THEN Conservation_Release_N+Thermal_Release_From_N ELSE 0

Thermal_and_Conservation_Rel_P = IF Total_Withdrawal_from_ERB<=Total_Conservation_Release_cf+Total_Thermal_Release_cf THEN Conservation_Release_P+Thermal_Release_from_P ELSE 0

Total_Withdrawal_from_ERB = IF Day_of_Year>=0 AND Day_of_Year<=365 AND Total_Cum_Thermal_Rel+Total_Cum_Augmented_Rel<Total_Excess_Release*bg_to_cf THEN Total_Thermal_Release_cf+Total_Conservation_Release_cf ELSE 0

A.31. Total Conservation Release

Total_Conservation_Release_cf = Conservation_Release_Can+Conservation_Release_N+Conservation_Release_P

Total_Cum_Augmented_Rel = Cum_Augmented_Rel+Cum_Augmented_Rel_Can+Cum_Augmented_Rel_N

A.32. Cumulative Releases

Total_Cum_Excess_Rel = IF TIME>8545 THEN (Cum_excess_release_rev1+Cum_excess_release_rev4)-(ERB_REV7) ELSE Cum_excess_release_rev1+Cum_excess_release_rev4

Total_Cum_Thermal_Rel = IF TIME>7788 AND TIME<8138 OR Combined_Storage<=Normal_Storage_Level_bg*1000 AND Combined_Storage>Drought_Warning_Rev_4_bg*1000 THEN (Cumulative_thermal_release_P+Cum_thermal_rel_C+cum_thermal_rel_N)*0.85 ELSE IF TIME>7788 AND TIME<8138 OR Combined_Storage<Drought_Warning_Rev_4_bg*1000 AND

Combined_Storage>=Drought_bg*1000 THEN 0 ELSE

Cumulative_thermal_release_P+Cum_thermal_rel_C+cum_thermal_rel_

Appendix B Exceptions for The Minimum Flow Requirements at Montague, NJ

This appendix presents the minimum flow requirements at Montague, NJ based on the design data of Report of the River Master of the Delaware River, and amended schedules by the Delaware River Basin Commission (DRBC) under drought emergency conditions.

B.1. The Minimum Flow Requirements at Montague, NJ (Report of the River Master of the Delaware River)

The minimum flow targets in Montague from 1981 to 1983 are considered in the model based on the Delaware River Master Report (ODRM, 2016). The flow target schedule for Montague, NJ based on the design data of Report of the River Master of the Delaware River is given in Table B.1-1.

Table B.1-1 The minimum flow requirement at Montague based on the design data of the River Master for 1981, 1982 and 1983 (ODRM, 2016)

Time	Release Rate at Montague (cfs)		
	1981	1982	1983
Jan 18 - Feb 22	1,350	1,750	1,550
Feb 23 – March 27	1,100	1,750	1,550
March 28 – April 27	1,100	1,750	1,750
April 28 – May 17	1,100	1,750	1,750
May 18 – June 14	1,750	1,750	1,750
June 15 – September 22	1,750	1,850	1,850
Sept 23 – Sep 24	1,750	1,850	1,750
Sep 25 – Oct 2	1,750	1,750	1,750
Oct 3 – Oct 4	1,750	1,850	1,750
Oct 5 – Oct 9	1,750	1,750	1,750
Oct 10 – Oct 11	1,750	1,850	1,750
Oct 12 – Oct 16	1,750	1,750	1,750
Oct 17 – Oct 18	1,750	1,850	1,750
Oct 19 – Oct 23	1,750	1,750	1,750
Oct 24 – Oct 25	1,750	1,850	1,750
Oct 26 – Oct 27	1,750	1,750	1,750
Oct 27 – Nov 8	1,750	1,850	1,750
Nov 9 – Nov 12	1,750	1,850	1,655
Nov 13 – Nov 30	1,750	1,655	1,655
Dec 1 – Dec 7	1,560	1,750	1,655
Dec 8 – Dec 19	1,560	1,750	1,550
Dec 20 – Dec 24	1,550	1,750	1,550
Dec 25 – Dec 26	1,550	1,700	1,550
Dec 27 – Dec 30	1,550	1,750	1,550
Jan 1 – Jan 17	1,550	1,750	1,550

B.2. Amended Montague Flow Target Schedule Under Drought Emergency Conditions

The Good Faith Agreement (GFA) established a schedule of phased reductions in the Montague flow objectives. The formula was based on a differentiation between normal, drought warning, and drought conditions. However, there were some exceptions during 24 years of operation. For example, the Montague flow targets established in the GFA was temporarily reduced in 1985 in order to store more water in the reservoirs during water supply emergency conditions. Therefore, on May 13, 1985, the DRBC declared a water supply emergency in the basin. The reservoir storage was in the drought-warning zone of the rule curve. Due to the water supply emergency, the target flow for Montague was 1,550 cfs in June 1, 1985. The DRBC, with the consent of the parties to the decree, passed a resolution to temporarily amend the release schedule at Montague in the GFA for periods of combined storage in the drought-warning zone. The target flow for Montague was reduced from 1,655 - 1,550 cfs to 1,600 – 1,300 cfs depending on the location of salt front. The amended schedule was placed in effect from July 25, 1985 to October 2, 1985 (Survey G., 1982). Savings in NYC reservoirs' storage achieving by reduction of the Montague flow objective was allocated among thermal emergency bank (25%), New Jersey Diversion Bank (25%), and Basin Bank (50%) (ODRM, 1985). The amended schedule for the minimum Montague flow target under drought emergency conditions is presented in Table B.2-2.

Table B.2-2 Streamflow objectives during periods of the combined storage of all NYC reservoirs within the drought-warning zone (Survey G., 1982)

7 - day average location of 'salt front'	Flow objective, Cubic Feet Per Second At Montague, N.J.		
	Dec - Apr	May - Aug	Sept - Nov
Upstream of R.M. 92.5	1600	1650	1650
Between R.M. 87.0 and R.M. 92.5	1350	1600	1500
Between R.M. 82.9 and R.M. 87.0	1350	1600	1500
Downstream of R.M. 82.9	1300	1350	1300

B.3. Section References

Office of Delaware River Master (ODRM), 2015. Report of the River Master of the Delaware River for the Period of December 1, 1984 – November 30, 1985. U.S. Geological Survey open file report 86-0606.

Office of Delaware River Master (ODRM), 2016. Retrieved from: http://water.usgs.gov/osw/odrm/releases.html

Survey, G. 1982. U.S. Geological Survey Water-supply Paper: U.S. Government Printing Office.

Appendix C Historical Reservoir Operation Rules

This appendix presents historical reservoir operation rules used in the model and established by the DRBC.

DOCKET NO. D-77-20

DELAWARE RIVER BASIN COMMISSION

Experimental Modification to the
Current Release Schedules from
Cannonsville, Pepacton and Neversink Reservoirs

Delaware and Sullivan Counties, New York

PROCEEDINGS

The New York State Department of Environmental Conservation proposed regulations to modify the existing schedule of conservation releases from Cannonsville, Pepacton and Neversink Reservoirs. Title 8, Article 15 of the New York State Environmental Conservation Law requires the promulgation of rules and regulations for these and other reservoir releases.

The Delaware River Basin Commission held a hearing on February 23, 1977, on the proposed rules to regulate releases from Cannonsville, Pepacton, and Neversink Reservoirs. The hearing included testimony on the proposed regulations by the New York State Department of Environmental Conservation and modified proposals by New York City, Delaware River Basin Commission and the Pennsylvania Department of Environmental Resources. Considering the testimony presented, the Delaware River Basin Commission proposes the following experimental program be approved under Section 3.8 of the Compact.

EXPERIMENTAL PROGRAM

It is proposed to conduct an experimental modification of existing reservoir schedules from June 1, 1977 to May 31, 1979, to test potential benefits and impacts of revised conservation and excess release schemes. The experiment will be subject to annual review by the Delaware River Basin Commission and the City of New York and may be extended for one additional year if desirable and upon agreement of all parties to the United States Supreme Court Decree entered in New Jersey v. New York, 347 U. S. 995 (1954). The experimental program contains the following basic elements:

A. Excess Release Bank

For the experimental period, an excess release bank would be established, based on the amount calculated under Art. III, paragraph B, 1, (c), of the 1954 Decree for excess releases, "equal to 83 percent of the amount by which the estimated consumption for each calendar year is less than the City's estimate of the continuous safe yield during such year of all its sources obtainable without pumping." The estimated amount available in the bank for 1977-78 totals approximately 31 billion gallons.

B. Conservation Release Program

In place of the existing New York City schedule of conservation releases and the excess release schedule provided under Art. III, paragraph B, 1, (d) of the 1954 Decree, a new conservation release schedule on a year-round basis will be established. Under this schedule, the minimum releases from the Cannonsville, Pepacton and Neversink reservoirs will be as follows:

	April 1 - June 14 Aug. 16 - Oct. 31	June 15 - Aug. 15	Nov. 1 - March 31
Neversink	45 cfs*	45 cfs	25 cfs
Pepacton	70	70	50
Cannonsville	45	325	33
	160 cfs	440 cfs	108 cfs

* cubic feet per second

These total conservation releases break down as follows:

TABLE I

Reservoir and Operative Dates	Column 1 Existing Conservation Release	+	Column 2 Proposed Augmented Conservation Release	=	Column 3 Total New Conservation Release
Neversink					
4/1 - 4/7	5 cfs		40 cfs		45 cfs
4/8 - 10/31	15		30		45
11/1 - 3/31	5		20		25
Pepacton					
4/1 - 4/7	6		64		70
4/8 - 10/31	19		51		70
11/1 - 3/31	6		44		50
Cannonsville					
4/1 - 4/15	8		37		45
4/16 - 6/14	23		22		45
6/15 - 8/15	23		302		325
8/16 - 10/31	23		22		45
11/1 - 11/30	23		10		33
12/1 - 3/31	8		25		33

C. Basic Montague Release

At all times, New York City would be required to make such releases as directed by the River Master designed to maintain a minimum basic flow of 1750 cfs at the Montague gaging station, as already required by the Decree.

D. Special Thermal Stress Releases

Special releases may be made from one or more of the reservoirs in order to relieve thermal stress conditions which pose a threat to fisheries. The total volume of such releases shall not exceed 6,000 cfs-days from all reservoirs. Thermal releases, with a one-day lead time, would be made whenever the maximum water temperature at Callicoon, Harvard, Woodbourne or Hale Eddy is projected to exceed a maximum of 75°F, or a 72°F daily average. If the 6,000 cfs-days reserve is not used by October 31 of any year it will not be used thereafter. No releases for relieving thermal stress would be required from November 1 to May 31 of any year.

E. Withdrawals from Excess Release Bank - Daily Accounting

The augmented conservation releases provided under Part B and the special thermal stress releases provided under Part D, shall not exceed the total quantity in the excess release bank during any water year, commencing on June 1. Releases required to maintain the minimum basic flow of 1750 cfs at Montague or required under existing conservation release schedules when releases are not directed for a minimum basic rate at Montague of 1750 cfs, would not be counted against the excess release bank.

The daily accounting procedure for calculating daily credits and deficits to the excess release bank during the water year commencing June 1 shall be developed by the River Master with unanimous approval by the parties to the Decree.

FINDINGS

In the long-term, as New York City consumption increases, the amount of excess release capacity in the Delaware Reservoir System will diminish. Thus, any long-range release program must be based on arrangements which will not rely on reallocation of excess releases calculated under Art. III, paragraph B, 1, (c) of the 1954 Decree. Moreover, the basin states face the continuing problem regarding the inability of the Decree to function as originally designed during extreme drought emergencies. A long-term plan to define drought emergency conditions and to prescribe the conservation measures necessary to protect all interested parties during such conditions is required to address this problem.

Therefore, as a condition upon approval of the modified conservation releases, the Commission will undertake during the experimental period (June 1, 1977 to May 31, 1979) the following tasks to develop a long-range program for reservoir operations in the upper basin.

A. Drought Emergency Criteria and Conservation Measures

1. A task group including all the parties to the 1954 Decree should develop and prepare for Commission approval criteria defining the onset and stages of drought or water shortage emergencies. Such criteria may include consideration of reservoir storage levels, stream flow and groundwater conditions, meteorologic predictions, and other relevant data indicative of drought existence and actual or predicted severity.

2. The task group should also prepare an emergency diversion, water allocation and release plan specifying actions which the Commission would intend to take at various stages of a future emergency. The plan should include consideration of conservation measures which may be taken by various users, and the results of the salinity and estuary pollution assimilation model studies now in progress.

3. The task group should explore the operation of the total New York City system to assure under emergency conditions the maximum possible conservation of waters stored in the Delaware System reservoirs and balanced use of supplies available throughout the City system.

B. Long-Term Reservoir Operations Scheme

1. The program for reservoir operations must give priority to meeting the release requirements at the Montague gauge and the water supply requirements of New York City and the municipalities dependent upon the Delaware reservoirs. Along with an emergency plan, a long-term program for reservoir operations and stream flow maintenance should be developed through the cooperative efforts of the concerned parties. This program should include alternatives for sustaining conservation flows as excess release capacity diminishes in the City system.

2. As part of the long-term plan, consideration should be given to means of achieving more coordinated releases from all upper basin reservoirs, including private power facilities, in order to reduce adverse fluctuations in flows experienced by various basin streams. The total upper basin should be approached as a system, to be studied in a cooperative fashion by all concerned public and private interests.

3. The long-term reservoir operations scheme must be closely coordinated with the Level B, salinity and estuary studies to assure maximum benefits for the basin as a whole.

Staff of the Delaware River Basin Commission prepared an environmental assessment of the proposed experimental program. The assessment states in the final conclusion;

> "Therefore, in view of the significance of known beneficial effects of the proposal, its temporary duration, the unlikelihood of significant adverse impacts and the probability that they are reversible should they occur, it is concluded that an environmental impact statement is not warranted for action on the proposal, and that, pursuant to Sec. 2-4.5 of the Delaware River Basin Commission's Rules of Practice and Procedure, the Executive Director, issue a negative declaration."

A negative declaration was issued on April 27, 1977 by the Execututve Director.

The proposed project does not conflict with nor adversely affect the Comprehensive Plan.

There are no properties listed in the National Register of Historic Places at the project site or directly adjacent that will be affected by the action of the Delaware River Basin Commission.

The New York State Department of Environmental Conservation's Part 671 Regulations entitled Reservoir Releases Regulations - Cannonsville, Pepacton and Neversink Reservoirs dated May 16, 1977, are consistent with this proposed docket decision.

DECISION

The project, as described above, is approved pursuant to Section 3.8 of the Compact, subject to the following conditions:

A. All signatory parties to the Delaware River Basin Compact agree to abide by the conditions and requirements as stated in the above described experimental program and long-range program.

B. Releases Under Emergency Conditions

The Commission retains its power under Section 3.3(a) and Article 10 of the Compact to declare a drought emergency after consultation with the River Master, in order to conserve the waters in the Delaware River and its tributaries and in the reservoirs of the Upper Delaware River Basin, in order to protect water supply, health and safety of the residents of the Delaware River Basin and its service area. The River Master retains all of his powers under the Decree including the powers under Article VII, B.1 of the 1954 Decree to conserve the waters in the river, its tributaries, and in reservoirs owned by the City of New York, or in reservoirs developed by other parties to the Decree after 1954.

C. Monitoring

1. The purpose of this experimental program is to assess the possible benefits and adverse impacts of a modified release schedule. During this period, the New York State Department of Environmental Conservation, Commission and agencies of the other signatory parties shall monitor the impacts on fisheries, recreational uses, water shortage and yields of the New York City reservoirs, and estuary regimes (particularly salinity). Plans for a detailed monitoring program shall be submitted to and be approved by the Commission as a condition upon the release program.

2. A monthly status report of reservoir operations, storage levels, and releases implemented under the program shall be reviewed by the Commission. The report should include a comparison of releases and Montague flows under the experimental program with releases and Montague flows which would have otherwise been experienced under the existing Decree/conservation release scheme. The running total of the excess conservation release bank withdrawals will be continuously monitored by the Commission.

D. This approval is contingent upon the unanimous consent of the parties to the United States Supreme Court Decree entered in New Jersey v. New York, 347 U. S. 995 (1954) as set forth in a Memorandum of Agreement together with the approval of the Delaware River Master.

E. This approval shall expire May 31, 1979, unless it shall be extended for an additional one year upon agreement of all parties.

BY THE COMMISSION

DATED: May 25, 1977

DOCKET NO. D-77-20 CP (REVISED)

DELAWARE RIVER BASIN COMMISSION

MODIFICATION TO THE RELEASE SCHEDULES FROM
CANNONSVILLE, PEPACTON, AND NEVERSINK RESERVOIRS
DELAWARE AND SULLIVAN COUNTIES, NEW YORK

Proceedings

The New York State Department of Environmental Conservation (NYDEC) adopted regulations in 1977 to modify the schedule of conservation releases from Cannonsville, Pepacton, and Neversink Reservoirs. The regulations provided for the new schedule of releases to be tried on a limited experimental basis.

The Delaware River Basin Commission (DRBC) approved the experimental release program on May 25, 1977, by Docket decision D-77-20 and extended that approval through May 31, 1983, by Resolution 82-7. Docket decision D-77-20 also directed the parties to the 1954 Decree to develop criteria defining the onset and stages of drought emergencies.

NYDEC proposes to amend the experimental regulations by removing the automatic termination date, deleting the relationship to the "excess quantity" as established by the U.S. Supreme Court Decree (347 U.S. 995 (1954)) and limiting releases according to a reservoir storage curve in time of drought warning and drought.

Research findings and comments from fishermen and recreationists indicate that the program has had a beneficial effect. The DRBC held a hearing on May 28, 1980, on the amended release regulations and a proposal that the Commission's approval of the schedule of augmented releases be made permanent.

Reservoir Release Program

A. New Conservation Releases

In place of the previous New York City schedule of conservation releases, a new conservation release schedule on a year-round basis has been tried as an experimental program and is proposed to be continued on a permanent basis. Under this schedule, the minimum releases from Cannonsville, Pepacton, and Neversink Reservoirs will be as follows:

	April 1 - June 14 Aug. 16 - Oct. 31	June 15 - Aug. 15	Nov. 1 - March 31
Neversink	45 cfs*	45 cfs	25 cfs
Pepacton	70	70	50
Cannonsville	45	325	33
	160 cfs	440 cfs	108 cfs

*cubic feet per second

These total conservation releases break down as follows:

TABLE 1

Reservoir and Operative Dates	Column 1 Basic Conservation Release	+	Column 2 Proposed Augmented Conservation Release	=	Column 3 Total New Conservation Release
Neversink					
4/1 - 4/7	5 cfs		40 cfs		45 cfs
4/8 - 10/31	15		30		45
11/1 - 3/31	5		20		25
Pepacton					
4/1 - 4/7	6		64		70
4/8 - 10/31	19		51		70
11/1 - 3/31	6		44		50
Cannonsville					
4/1 - 4/15	8		37		45
4/16 - 6/14	23		22		45
6/15 - 8/15	23		302		325
8/16 - 10/31	23		22		45
11/1 - 11/30	23		10		33
12/1 - 3/31	8		25		33

B. Basic Montague Release

At all times, New York City would be required to make such relases as directed by the River Master designed to maintain a minimum basic flow of 1750 cfs at the Montague gaging station, or the excess release rate during the seasonal period, as already required by the Decree.

C. Special Thermal Stress Releases

Special relases may be made from one or more of the reservoirs in order to relieve thermal stress conditions which pose a threat to fisheries. The total volume of such releases shall not exceed 6,000 cfs-days from all reservoirs. Thermal releases, with a one-day lead time, would be made whenever the maximum water temperature in designated downstream areas as determined from measurements at Callicoon, Harvard, Woodbourne, or Hale Eddy is projected to exceed a maximum of 75°F, or a 72°F daily average. If the 6,000 cfs-days reserve is not used by October 31 of any year it will not be used thereafter. No releases for relieving thermal stress would be required from November 1 to April 30 of any year. Releases for purposes of relieving thermal stress shall be at the direction of NYDEC.

D. Drought Warning and Drought Conditions

The augmented conservation release will be reduced to the basic conservation release (shown in Table 1) during drought warning and drought periods as defined by the attached reservoir storage curves marked "Operation Curves for Cannonsville, Pepacton, and Neversink Reservoirs" (page 29) except that when the Delaware River Master directs releases according to the provisions in the 1954 U.S. Supreme Court Decree, New York City shall make such releases from Cannonsville, Pepacton, and Neversink Reservoirs as are necessary and sufficient to maintain the constant minimum flows specified in "A" above on the West Branch Delaware River, East Branch Delaware River, and the Neversink River, and provided that the total amount of water released from the three reservoirs does not exceed the amount directed by the Delaware River Master. If the amount of directed releases by the River Master is not sufficient to maintain the augmented releases from all three reservoirs, the releases from each reservoir will be determined at the discretion of NYDEC and New York City -- Department of Environmental Protection (NYC - DEP).

Conservation releases shall be returned to normal augmented levels following a drought. Return to normal augmented levels shall not be made unless and until combined storage in the three reservoirs reaches 25 billion gallons above the drought warning level, as shown by the attached reservoir storage curves (page 29), and remains at or above that level for 15 consecutive days.

Findings

The NYDEC's Amended Part 671 Regulations entitled, Reservoir Release Regulations: Cannonsville, Pepacton, and Neversink Reservoirs adopted May 2, 1980, are consistent with this proposed action.

The Monitoring and Evaluation Program during the experimental reservoir release period has been reported in two performance reports by NYDEC. One for the year July 1, 1977, through June 30, 1978, and a second for the July 1, 1978 through December 31, 1979 period. These evaluations indicate that the conservation release program has been very effective and beneficial and should be continued. The report includes an estimate that an additional 52,500 -- 65,500 angler-trips annually could result from the release program. The economic value of these additional angler trips could range from $1,650,000 to $2,066,000 annually.

The project does not conflict with nor adversely affect the Comprehensive Plan. It provides beneficial use of the water resources and does not adversely influence the present or future use and development of the water resources of the Basin.

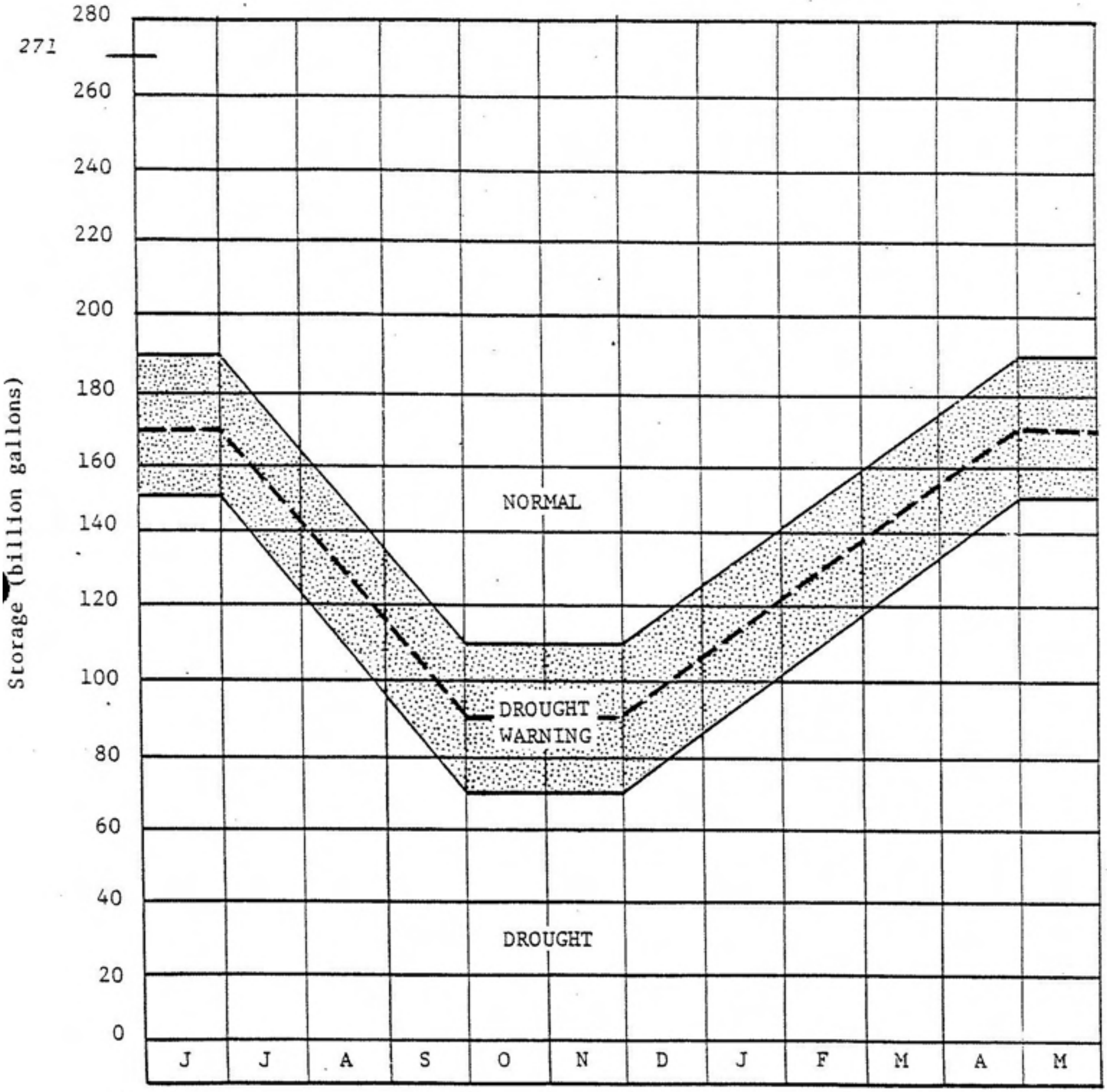
Decision

I. The project, as described above, with modifications specified hereinafter, is hereby added to the Comprehensive Plan.

II. The project is approved pursuant to Section 3.8 of the Compact, subject to the following conditions:

a. Approval is subject to all conditions imposed by NYDEC.

OPERATION CURVES FOR
CANNONSVILLE, PEPACTON AND NEVERSINK RESERVOIRS



DOCKET NO. D-77-20 CP (REVISION NO. 2)

DELAWARE RIVER BASIN COMMISSION

Modifications To The Schedule Of Release Rates From Pepacton and Neversink Reservoirs
Delaware and Sullivan Counties, New York

PROCEEDINGS

This is an application submitted by the New York State Department of Environmental Conservation (NYS DEC) for approval of a revised schedule of augmented conservation release rates from Pepacton and Neversink Reservoirs to be tried on an experimental basis for up to three years (June 1993 - May 1996).

The current schedule of augmented conservation release rates from Cannonsville, Pepacton and Neversink Reservoirs was added to the Comprehensive Plan and approved by the Delaware River Basin Commission (DRBC) pursuant to Section 3.8 of the Compact on November 30, 1983 by Docket No. D-77-20 CP (Revision). The current release rates were established on an experimental basis first, and later made permanent by the DRBC and parties to the 1983 Good Faith Agreement. "Proceedings" leading to such actions are described in Docket No. D-77-20 CP (Revised). This application (including the Proposed Augmented Conservation Release rates) was reviewed for inclusion of the project in the Comprehensive Plan and approval under Section 3.8 of the Delaware River Basin Compact. A public hearing on this project was held by the DRBC on June 23, 1993.

RESERVOIR RELEASE PROGRAMS

A. **Proposed Conservation Releases.**

In order to further protect and enhance the recreational use of waters affected by releases from the Pepacton and Neversink Reservoirs, and based on the experience gained since the augmented reservoir release regulations were implemented, the following revisions to the current release rates are proposed for an experimental period of three years (June 1993 - May 1996):

TABLE 1

Reservoir and Operative Dates	Column 1 Basic Conservation Release	Column 2 Current Augmented Conservation Release	Column 3 Proposed Augmented Conservation Release
Pepacton			
1/1 - 3/31	6 cfs	50 cfs	45 cfs
4/1 - 4/7	6	70	45
4/8 - 4/30	19	70	45
5/1 - 5/31	19	70	70
6/1 - 8/31	19	70	95
9/1 - 9/30	19	70	70
10/1 - 10/31	19	70	45
11/1 - 12/31	6	50	45
Neversink			
1/1 - 3/31	5 cfs	25 cfs	25 cfs
4/1 - 4/7	5	45	25
4/8 - 4/30	15	45	25
5/1 - 9/30	15	45	53
10/1 - 10/31	15	45	25
11/1 - 12/31	15	25	25
Cannonsville			
4/1 - 4/15	8 cfs	45 cfs	Same as Column 2.
4/16 - 6/14	23	45	[Outlet Works Facility currently has release valve limitations.]
6/15 - 8/15	23	325	
8/16 - 10/31	23	45	
11/1 - 11/30	23	33	
12/1 - 3/31	8	33	

B. <u>Basic Montague Release</u>.

At all times, New York City would be required to make such releases as directed by the River Master designed to maintain a minimum basic flow of 1,750 cfs at the Montague gaging station, or the excess release rate during the seasonal period, as already required by the 1954 U.S. Supreme Court Decree.

C. <u>Special Thermal Stress Releases</u>.

Special releases may be made from one or more of the reservoirs in order to relieve thermal stress conditions which pose a threat to fisheries. The total volume of such releases shall not exceed 6,000 cfs-days from all reservoirs. As set forth in Docket No. D-77-20 CP (REVISION), thermal releases, with a one-day lead time, would be made whenever the maximum water temperature in designated downstream areas as determined from measurements at Callicoon, Bridgeville, Woodbourne, or Hale Eddy is projected to exceed a maximum of 75° F, or a 72° F daily average. If the 6,000 cfs-days reserve is not used by October 31 of any year, it will not be used thereafter. No releases for relieving thermal stress would be required from November 1 to April 30 of any year. Releases for purposes of relieving thermal stress shall be at the direction of NYS DEC.

D. <u>Drought Warning and Drought Conditions</u>.

The augmented conservation release will be reduced to the basic conservation release (shown in Table 1, Column 1) during drought warning and drought periods as defined by the attached reservoir storage curves entitled "Operation Curves for Cannonsville, Pepacton, and Neversink Reservoirs" (Figure 1) except that when the Delaware River Master directs releases according to the provisions in the basinwide drought plan as adopted in DRBC Resolution 83-13, New York City shall make such releases from Cannonsville, Pepacton, and Neversink Reservoirs as are necessary and sufficient to maintain the constant minimum flows (specified in Table 1, Column 3) on the West Branch Delaware River, East Branch Delaware River, and the Neversink River, and provided that the total amount of water released from the three reservoirs does not exceed the amount directed by the Delaware River Master., If the amount of directed releases by the River Master is not sufficient to maintain the augmented releases from all reservoirs, the releases from each reservoir will be determined at the discretion of NYS DEC and New York City-Department of Environment Protection (NYC DEP).

Following a drought, a return to the proposed augmented conservation release rates shown in Column 3 of Table 1 shall not be made unless and until combined storage in the three reservoirs reaches 25 billion gallons above the drought warning level, as shown in Figure 1, and remains at or above that level for 15 consecutive days.

As documented in Docket No. D-77-20 CP (REVISION), the NYS DEC evaluations, to date concerning the monitoring program, indicate that the augmented conservation release program has improved and extended fisheries downstream from the three New York City reservoirs, and other water-related recreational activities have shown increases since the initiation of the experimental program in 1977.

The project does not conflict with or adversely affect the Comprehensive Plan. It provides beneficial use of the water resources and does not adversely influence the present or future use and development of the water resources of the Basin.

DECISION

I. The project, as described above, with modifications specified hereinafter, is hereby added to the Comprehensive Plan.

II. The project is approved pursuant to Section 3.8 of the Compact, subject to the following conditions:

a. Monthly summaries of reservoir operations submitted by NYC DEP to NYS DEC shall also be submitted to the DRBC.

b. Detailed operational records of each reservoir, maintained by both the City and State Reservoir Release Managers, shall be available to the DRBC upon request.

c. The provisions of the reservoir release program approved herein shall not be applicable to any action taken by NYC DEP or NYS DEC with regard to the operation of the Cannonsville, Pepacton, or Neversink Reservoirs in any emergency situation where there is a threat to the continued existence or safe operation of the dams or tunnels or to any appurtenant structures or to the public health or safety. Any emergency action shall continue only for such time as is necessary to avert the threat and is subject to the approval of the Executive Director of the DRBC.

d. Increases in the augmented conservation release levels may not be made except in accordance with the allowances provided for in the Stipulation of Discontinuance in The City of New York vs. The State of New York Department of Environmental Conservation, Index No. 5840-80, and shall be subject to approval by the DRBC.

e. Releases under emergency conditions. The Commission retains its power under Section 3.3(a) and Article 10 of the Compact to declare a drought emergency after consultation with the River Master, in order to conserve the waters in the Delaware River and its tributaries and in the reservoirs of the Upper Delaware River Basin, in order to protect water supply, health, and safety of the residents of the Delaware River Basin and its service area. The River Master retains all of his powers under the Decree including the powers under Article VII, B.1 of the 1954 Decree to conserve the waters in the river, its tributaries, and in reservoirs owned by the City of New York, or in reservoirs developed by other parties to the Decree after 1954.

f. A progress report describing the results of the experimental program shall be submitted by August 1 of each year, beginning August, 1994.

BY THE COMMISSION

DATED: June 23, 1993

DOCKET NO. D-77-20 CP (Revision No. 3)

DELAWARE RIVER BASIN COMMISSION

Modifications to the Schedule of Release Rates from Cannonsville, Pepacton and Neversink Reservoirs Delaware and Sullivan Counties, New York

PROCEEDINGS

This is an application submitted by the New York State Department of Environmental Conservation (NYSDEC) for approval of a revised schedule of augmented conservation releases from Cannonsville Reservoir, and extension of the revised experimental release schedules for all the project reservoirs (Cannonsville, Pepacton and Neversink), to May, 2000.

The current schedule of experimental revised augmented conservation release rates from Pepacton and Neversink Reservoirs was added to the Comprehensive Plan and approved by the Delaware River Basin Commission (DRBC) pursuant to Section 3.8 of the Compact on June 23, 1993 by Docket No. D-77-20 CP (Revision No. 2). At that time, the release schedule proposed for Cannonsville Reservoir could not be implemented since its release valves did not have the necessary flexibility. New valves have been installed and a new experimental release schedule is now proposed. The existing augmented conservation release rates were established on an experimental basis first and later made permanent. "Proceedings" leading to such actions are described in Docket No. D-77-20 CP (Revised). This application (including the Proposed Augmented Conservation Release rates for Cannonsville Reservoir) was reviewed for inclusion of the project in the Comprehensive Plan and approval under Section 3.8 of the Delaware River Basin Compact. A public hearing on this project was held by the DRBC on February 26, 1997.

RESERVOIR RELEASE PROGRAMS

A. Proposed Conservation Releases.

In order to further protect and enhance the recreational use of waters affected by releases from the Cannonsville, Pepacton and Neversink Reservoirs, and based on the experience gained since the augmented reservoir release regulations were implemented, the following revisions to the current approved release rates are proposed. The release rates for Pepacton and Neversink Reservoirs are the same as those previously approved (Docket No. D-77-20 CP (Revision No. 2)) for an initial experimental period of three years and are herein to be extended for another period of three years; all experimental releases are therefore scheduled to continue to May, 2000.

TABLE 1

Reservoir and Operative Dates	Column 1 Basic Conservation Release	Column 2 Current Augmented Conservation Release	Column 3 Augmented Experimental Conservation Release
Pepacton			
1/1 - 3/31	6 cfs	50 cfs	45 cfs*
4/1 - 4/7	6	70	45 *
4/8 - 4/30	19	70	45 *
5/1 - 5/31	19	70	70 *
6/1 - 8/31	19	70	95 *
9/1 - 9/30	19	70	70 *
10/1 - 10/31	19	70	45 *
11/1 - 12/31	6	50	45 *
Neversink			
1/1 - 3/31	5 cfs	25 cfs	25 cfs*
4/1 - 4/7	5	45	25 *
4/8 - 4/30	15	45	25 *
5/1 - 9/30	15	45	53 *
10/1 - 10/31	15	45	25 *
11/1 - 12/31	5	25	25 *
Cannonsville			Proposed
4/1 - 4/15	8 cfs	45 cfs	4/1 - 5/31: 45 cfs**
4/16 - 6/14	23	45	
6/15 - 8/15	23	325	6/1 - 9/15: 160 cfs**
8/16 - 10/31	23	45	
11/1 - 11/30	23	33	
12/1 - 3/31	8	33	9/16 - 3/31: 45 cfs**

* Extended to May, 2000 (previously approved via Docket No. D-77-20 CP (Revision No. 2))
** Proposed herein

B. Basic Montague Release.

At all times, New York City would be required to make such releases as directed by the River Master designed to maintain a minimum basic flow of 1,750 cfs at the Montague gaging station, or the excess release rate during the seasonal period, as required by the 1954 U.S. Supreme Court Decree.

C. Special Thermal Stress Releases.

Special releases may be made from one or more of the reservoirs in order to relieve thermal stress conditions which pose a threat to fisheries. The total combined volume of thermal stress storage will increase from 6,000 cfs-days (as set forth in Docket No. D-77-20 CP (Revision)) to 9,200 cfs-days. Releases would be made whenever the maximum water temperature in designated downstream areas is projected to exceed a maximum temperature of 75° F, or a daily average of 72° F. Releases from the thermal stress bank can be used until October 31 of any year. No releases for relieving thermal stress would be required from November 1 to April 30 of any year. Releases for purposes of relieving thermal stress shall be at the direction of NYSDEC.

D. Drought Warning and Drought Conditions.

The augmented conservation release will be reduced to the basic conservation release (shown in Table 1, Column 1) during drought warning and drought periods as defined by the attached reservoir storage curves entitled "Operation Curves for Cannonsville, Pepacton, and Neversink Reservoirs" except that when the Delaware River Master directs releases according to the provisions in the basinwide drought plan as adopted in DRBC Resolution No. 83-13, New York City shall make such releases from Cannonsville, Pepacton, and Neversink Reservoirs as are necessary and sufficient to maintain the constant minimum flows (specified in Table 1, Column 3) on the West Branch Delaware River, East Branch Delaware River, and the Neversink River, and provided that the total amount of water released from the three reservoirs does not exceed the amount directed by the Delaware River Master., If the amount of directed releases by the River Master is not sufficient to maintain the augmented releases from all reservoirs, the releases from each reservoir will be determined at the discretion of NYSDEC and New York City Department of Environment Protection (NYCDEP).

Following a drought, a return to the experimental augmented conservation release rates shown in Column 3 of Table 1 shall not be made unless and until combined storage in the three reservoirs reaches 25 billion gallons above the drought warning level, as shown in Figure 1, and remains at or above that level for 15 consecutive days.

FINDINGS

Installation of new release valves for the Cannonsville Reservoir is complete and should provide the needed flexibility in making releases to enhance fisheries management.

During the experimental period, conservation releases from Cannonsville Reservoir, which are considered inadequate by NYSDEC, would be modified to:

1) Increase the winter releases from 33 cfs to 45 cfs curing November through March, beginning March 1, 1997.

2) Revise the duration and quantity of summer releases from 325 cfs during June 15 through August 15 to 160 cfs during June 1 through September 15,

3) Add the remaining 3,200 cfs days of the current annual quantity of releases to the thermal bank of 6,000 cfs days to meet thermal targets of 75° F (maximum) and 72° F (average) at Hale Eddy and Hankins.

On June 23, 1993, Docket No. D-77-20 CP (Revision No. 2) was approved with the current experimental release schedule for Pepacton and Neversink Reservoirs and included CONDITION Decision "f." which requires the applicant to submit a progress report describing the results of the experimental program. The last report was submitted along with the application for the addition of the Cannonsville Reservoir experimental release schedule, herein. The report is titled *Evaluation of Experimental Reservoir Releases from Pepacton Reservoir and Neversink Reservoir: 1994-1995*. The report concludes that there were modest improvements to trout habitat while the need for thermal releases was reduced in 1994 and 1995. Thermal regimes suitable for trout habitat occurred over longer reaches of the East Branch Delaware River. Beneficial results were also indicated for the Neversink River due to the experimental release schedule. Overall, the experimental releases also contributed to reduced usage of the thermal stress bank in 1994 and 1995, and the program was judged to be generally helpful in managing the tailwater portion of the East Branch Delaware and Neversink Rivers. Due to the difficulty in detecting and evaluating subtle changes in ecological conditions, along with the natural variability in these systems, adequate time for achieving measurable results needs to be provided. The extension of the experimental release program for Pepacton and Neversink Reservoirs, along with the new experimental release program for Cannonsville Reservoir, should help provide measurable results.

The project does not conflict with or adversely affect the Comprehensive Plan. It provides beneficial use of the water resources and does not adversely influence the present or future use and development of the water resources of the Basin.

DECISION

I. The project, as described above, with modifications specified hereinafter, is hereby added to the Comprehensive Plan.

II. The project is approved pursuant to Section 3.8 of the Compact, subject to the following conditions:

a. Monthly summaries of reservoir operations submitted by NYCDEP to NYSDEC shall also be submitted to the DRBC.

b. Detailed operational records of each reservoir, maintained by both the City and State Reservoir Release Managers, shall be available to the DRBC upon request.

c. The provisions of the reservoir release program approved herein shall not be applicable to any action taken by NYCDEP or NYSDEC with regard to the operation of the Cannonsville, Pepacton, or Neversink Reservoirs in any emergency situation where there is a threat to the continued existence or safe operation of the dams or tunnels or to any appurtenant structures or to the public health or safety. Any emergency action shall continue only for such time as is necessary to avert the threat and is subject to the approval of the Executive Director of the DRBC.

d. Increases in the augmented conservation release levels may not be made except in accordance with the allowances provided for in the Stipulation of Discontinuance in The City of New York vs. The State of New York Department of Environmental Conservation, Index No. 5840-80, and shall be subject to approval by the DRBC.

e. Releases under emergency conditions. The Commission retains its power under Section 3.3(a) and Article 10 of the Compact to declare a drought emergency after consultation with the River Master, in order to conserve the waters in the Delaware River and its tributaries and in the reservoirs of the Upper Delaware River Basin, in order to protect water supply, health, and safety of the residents of the Delaware River Basin and its service area. The River Master retains all of his powers under the Decree including the powers under Article VII, B.1 of the 1954 Decree to conserve the waters in the river, its tributaries, and in reservoirs owned by the City of New York, or in reservoirs developed by other parties to the Decree after 1954.

f. Prior to application for an extension or modification of the experimental release program, a report describing the results of the project shall be submitted.

BY THE COMMISSION

DATED: February 26, 1997

DOCKET NO. D-77-20 CP (Revision No. 4)

DELAWARE RIVER BASIN COMMISSION

Modifications to the Schedule of Release Rates from Cannonsville, Pepacton and Neversink Reservoirs Delaware and Sullivan Counties, New York

PROCEEDINGS

This is an application submitted by the New York State Department of Environmental Conservation (NYSDEC) for approval of an amendment to the revised schedule of augmented conservation releases. The proposed amendment is designed to reserve additional water storage that can be subsequently released for improving fisheries during times when the augmented releases are presently curtailed.

The current schedule of experimental revised augmented conservation release rates from Pepacton and Neversink Reservoirs was added to the Comprehensive Plan and approved by the Delaware River Basin Commission (DRBC) pursuant to Section 3.8 of the *Compact* on June 23, 1993 by Docket No. D-77-20 CP (Revision No. 2). At that time, the release schedule proposed for Cannonsville Reservoir could not be implemented since its release valves did not have the operational flexibility necessary. Afterwards, however, new valves were installed and a new experimental release schedule was approved; the current schedule of experimental augmented conservation release rates from Cannonsville Reservoir was added to the Comprehensive Plan and approved pursuant to Section 3.8 of the *Compact* on February 27, 1997 by Docket No. D-77-20 CP (Revision No. 3).

This application provides for the automatic banking of 50 percent of the yearly excess release quantity and the extension of the current experimental releases to coincide with the expiration of the amended releases program on April 30, 2001. This application was reviewed for inclusion of the project in the Comprehensive Plan and approval under Section 3.8 of the Delaware River Basin *Compact*. A public hearing on this project was held by the DRBC on April 28, 1999.

RESERVOIR RELEASE PROGRAMS

A. Current Augmented Conservation Releases.

Whenever the storage in the New York City Delaware River Basin Reservoirs is "Normal" as defined in DRBC Resolution No. 83-13, the experimental augmented conservation releases shall continue as described in DRBC Docket No. D-77-20 CP (Revision No. 3). (See Table 1A)

TABLE 1A

Reservoir and Operative Dates	Column 1 Basic Conservation Release	Column 2 Current Augmented Conservation Release	Column 3 Augmented Experimental Conservation Release
Pepacton			
1/1 - 3/31	6 cfs	50 cfs	45 cfs
4/1 - 4/7	6	70	45
4/8 - 4/30	19	70	45
5/1 - 5/31	19	70	70
6/1 - 8/31	19	70	95
9/1 - 9/30	19	70	70
10/1 - 10/31	19	70	45
11/1 - 12/31	6	50	45
Neversink			
1/1 - 3/31	5 cfs	25 cfs	25 cfs
4/1 - 4/7	5	45	25
4/8 - 4/30	15	45	25
5/1 - 9/30	15	45	53
10/1 - 10/31	15	45	25
11/1 - 12/31	5	25	25
Cannonsville			
4/1 - 4/15	8 cfs	45 cfs	4/1 - 5/31: 45 cfs
4/16 - 6/14	23	45	
6/15 - 8/15	23	325	6/1 - 9/15: 160 cfs
8/16 - 10/31	23	45	
11/1 - 11/30	23	33	
12/1 - 3/31	8	33	9/16 - 3/31: 45 cfs

B. Proposed Excess Release Banking.

As a means to further increase the amount of water storage available for release for fisheries enhancement during this experimental augmented conservation release program, 50 percent of the annual excess release quantity shall be automatically held and placed into a "fisheries protection bank". This fisheries protection bank shall be available to augment releases during drought warnings (see "D" below). The remainder of the excess release quantity shall be utilized to provide a proportionally-reduced increase in the Montague flow objective according to the current procedures, or may be banked in accordance with the procedures outlined in the Lower Basin Drought Management Plan.

C. Proposed Drought Watch.

The seasonally segmented line (shown as dashes) splitting the current "Drought Warning" in *Figure 1* of DRBC Resolution No. 83-13 and DRBC Docket No. D-77-20 CP (Revised) is temporarily raised by four (4) billion gallons during the entire year. In addition, the upper half of the drought warning, previously referred to as DWI, is temporarily renamed Drought Watch. Operations during the renamed Drought Watch shall continue to limit the diversion by New York City to 680 million gallons per day (mgd) and reduce the Montague and Trenton flow targets to 1,655 cubic feet per second (cfs) and 2,700 cfs, respectively. Conservation releases will decrease to 85 percent of the augmented experimental level, the remaining thermal stress bank will be reduced by 15 percent, and the New Jersey diversion will remain at 100 mgd.

D. Drought Warning.

The lower half of the drought warning (DW2), based upon the rule curves included in DRBC Resolution No. 83-13 and as temporarily modified by "C" above, is designated Drought Warning, with diversions and flow targets conforming to DRBC Resolution No. 83-13 for the former DW2. The fisheries protection bank shall be used to provide conservation releases at the current summer baseline levels and additional emergency releases, as needed.

E. Drought Emergency.

The Drought Emergency provision shall remain at the levels designated in DRBC Resolution No. 83-13.

F. Balancing Adjustment.

In order to conserve water, the Delaware River Master is requested to utilize a balancing adjustment when calculating the releases to be directed to meet the Montague target. Additionally, during drought warning, the amount of the conservation releases from the New York City Delaware River Basin Reservoirs that is above the basic conservation release rates shall be considered as directed releases for the purpose of calculating the balancing adjustment.

FINDINGS

The experimental augmented conservation release rates program has significantly improved NYSDEC's ability to control the minimum flow and the maximum temperatures downstream of the Cannonsville, Pepacton and Neversink Reservoirs. However, the current experimental augmented release rates program may not provide adequate flows to protect the fisheries during drought warning and drought emergency. The proposed revisions should significantly increase New York State's ability to manage trout habitat conditions during many drought conditions.

DECISION

I. The "Modification to the Schedule of Release Rates from Cannonsville, Pepacton and Neversink Reservoirs", Docket No. D-77-20 CP (Revision No. 3), including the modifications herein, are hereby extended until April 30, 2001.

II. The Comprehensive Plan is hereby amended to include the revisions described above with the modifications specified hereinafter.

III. The amended project, as described above, is approved pursuant to Section 3.8 of the *Compact*, subject to the following conditions:

a. Monthly summaries of reservoir operations submitted by NYCDEP to NYSDEC shall also be submitted to the DRBC.

b. Detailed operational records of each reservoir, maintained by both the City and State Reservoir Release Managers, shall be available to the DRBC upon request.

c. The provisions of the reservoir release program approved herein shall not be applicable to any action taken by NYCDEP or NYSDEC with regard to the operation of the Cannonsville, Pepacton, or Neversink Reservoirs in any emergency situation where there is a threat to the continued existence or safe operation of the dams or tunnels or to any appurtenant structures or to the public health or safety. Any emergency action shall continue only for such time as is necessary to avert the threat and is subject to the approval of the Executive Director of the DRBC.

d. Increases in the augmented conservation release levels may not be made except in accordance with the allowances provided for in the Stipulation of Discontinuance in *The City of New York vs. The State of New York Department of Environmental Conservation*, Index No. 5840-80, and shall be subject to approval by the DRBC.

e. Releases under emergency conditions. The Commission retains its power under Section 3.3(a) and Article 10 of the *Compact* to declare a drought emergency after consultation with the River Master, in order to conserve the waters in the Delaware River and its tributaries and in the reservoirs of the Upper Delaware River Basin, in order to protect water supply, health, and safety of the residents of the Delaware River Basin and its service area. The River Master retains all of his powers under the Decree including the powers under Article VII, B.1 of the 1954 Decree to conserve the waters in the river, its tributaries, and in reservoirs owned by the City of New York, or in reservoirs developed by other parties to the Decree after 1954.

f. Prior to application for an extension or modification of the experimental release program, a report describing the results of the project shall be submitted.

g. This experimental augmented conservation release rates plan may be revisited during any meeting of the parties to the 1954 Supreme Court Decree that is convened pursuant to DRBC Resolution No. 83-13 as a result of below-normal hydrologic conditions.

h. This revised experimental augmented conservation release rates program will automatically terminate on April 30, 2001 unless extended by agreement of all parties to the Decree.

i. The redesignation of the upper portion of drought warning (DWI) to drought watch will not change the compensation release requirements from Merrill Creek Reservoir. For the duration of this fisheries protection plan, the Delaware River Master, in cooperation with the DRBC, will track the operation of Merrill Creek Reservoir and compare the number of days of compensation releases and the volume of compensation releases from the Reservoir to those which would have occurred under the current plan as set forth in DRBC Resolutions Nos. 83-13 and 88-2 (Revised). If the difference in the number of days of compensation releases for any period June 15 to the following March 14 exceeds three days, the Commission shall determine the means by which the additional impact on Merrill Creek Reservoir shall be mitigated.

j. The operation of any project or facility previously approved by DRBC, with a reference to Drought Warning, is not altered or revised by the change in name from Drought Warning to Drought Watch.

BY THE COMMISSION

DATED: April 28, 1999

NO. 2002-6

DOCKET NO. D-77-20 CP (Revision 5)

DELAWARE RIVER BASIN COMMISSION

A RESOLUTION to extend Docket No. D-77-20 CP (Revision 4) for one year to continue the experimental augmented conservation release program for the New York City Delaware Basin Reservoirs, and to amend Docket No. D-77-20 CP (Revision 4) to establish a temporary habitat bank for support of experimental flow targets for fisheries protection on the West Branch of the Delaware River at Hale Eddy, and to temporarily modify the conservation releases from Cannonsville Reservoir.

WHEREAS, Docket No. D-77-20 CP (Revision 4) specified the current augmented experimental release program and instituted a drought watch and a revised drought warning level for the three New York City Delaware Basin Reservoirs beginning in May 1999 and ending on April 30, 2001; and

WHEREAS, Resolution No. 2001-5 extended Docket No. 77-20 CP (Revision 4) for one calendar year ending on April 30, 2002, and

WHEREAS, Docket No. D-77-20 CP (Revision 4) condition h. provides for an extension of the provisions of this Docket upon agreement of all parties to the 1954 Supreme Court Decree; and

WHEREAS, the parties to the 1954 Supreme Court Decree are in the process of negotiating a permanent fisheries release program more responsive to the water conditions downstream of New York City Delaware Basin Reservoirs; and

WHEREAS, agreement on the permanent fisheries release program is not expected prior to April 30, 2002, the date at which the current program will automatically terminate; and

WHEREAS, the State of New York has proposed a revision and extension to Docket No. D-77-20 CP (Revision 4) for one calendar year ending April 30, 2003; and

WHEREAS, the requested revision and extension has been agreed to by all parties to the 1954 Supreme Court Decree;

BE IT RESOLVED by the undersigned Commissioners and Parties to the Decree:

1. The Parties to the 1954 Supreme Court Decree agree that development of a viable permanent fisheries release program requires consideration of other related issues, including interbasin transfer policy, Good Faith operations, the DRBC Comprehensive Plan currently being developed, New York City participation, and procedures for computing the Excess Release Quantity.

2. Docket No. D-77-20 CP (Revision 4) is hereby extended for one year to April 30, 2003, with the following modifications.

   A. A "Habitat Bank" is established, which shall consist of 5,700 cfs-days that shall be contributed for one year only from the Excess Release Quantity (ERQ) as the ERQ is currently computed and such quantity of water as may be transferred from the Thermal Release Bank (which shall be credited on May 1, 2002 and expires on October 31, 2002) from time to time as may be necessary. The 5,700 cfs-days from the ERQ shall be credited on June 15, 2002, and any water remaining from that quantity shall expire on March 15, 2003.

   B. Upon entry into "Drought Watch", the remaining Thermal Release Bank shall be reduced by 15 percent.

   C. Upon entry into "Drought Warning", the remaining Thermal Release Bank shall be suspended until storage in the New York City Delaware River Basin Reservoirs is 25 billions gallons (bg) above the drought watch line for 15 consecutive days.

   D. The Habitat Bank shall be used only to meet the following targets in the West Branch Delaware River at Hale Eddy:

      During Normal Conditions - 225 cfs
      During Watch Conditions - 190 cfs
      During Warning Conditions - 150 cfs

   E. Upon entry into Drought Emergency, the Habitat Bank shall be suspended until storage in the New York City Delaware River Basin Reservoirs is 25 bg above the drought watch line for 15 consecutive days.

   F. Conservation releases from Cannonsville Reservoir shall be:

      During Normal Conditions - 45 cfs
      During Drought Watch Conditions - 35 cfs
      During Drought Warning Conditions - 23 cfs
      During Drought Emergency Conditions - 8 - 23 cfs

G. Comparison of the difference between releases from the Habitat Bank and the conservation releases under D-77-20 CP (Revision 4) will be made and the difference debited or credited to the habitat bank. However, a negative balance in the Habitat Bank is not allowed.

H. All other conditions shall continue as specified in Docket No. D-77-CP (Revision 4).

I. This resolution takes effect immediately and will expire on May 1, 2003.

J. No additional water beyond that specified in this resolution will be made available.

3. These specific conservation releases are not available when coming out of the present drought emergency until storage is 25 bg above the drought watch line for 15 consecutive days.

/s/ Col. John P. Carroll
Col. John P. Carroll, Chairman pro tem

/s/ Pamela M. Bush
Pamela M. Bush, Esq., Commission Secretary

ADOPTED: April 3, 2002

NO. 2002-21

DOCKET NO. D-77-20 CP (Revision 5) (Amended)

DELAWARE RIVER BASIN COMMISSION

A RESOLUTION to extend Docket No. D-77-20 CP (Revision 4) for one year to continue the experimental augmented conservation release program for the New York City Delaware Basin Reservoirs, and to amend Docket No. D-77-20 CP (Revision 4) to establish a temporary habitat bank for support of experimental flow targets for fisheries protection on the West Branch of the Delaware River at Hale Eddy, and to temporarily modify the conservation releases from Cannonsville Reservoir.

WHEREAS, Docket No. D-77-20 CP (Revision 4) specified the current augmented experimental release program and instituted a drought watch and a revised drought warning level for the three New York City Delaware Basin Reservoirs beginning in May 1999 and ending on April 30, 2001; and

WHEREAS, Resolution No. 2001-5 extended Docket No. 77-20 CP (Revision 4) for one calendar year ending on April 30, 2002, and

WHEREAS, Docket No. D-77-20 CP (Revision 4) condition h. provides for an extension of the provisions of this Docket upon agreement of all parties to the 1954 Supreme Court Decree; and

WHEREAS, the parties to the 1954 Supreme Court Decree are in the process of negotiating a permanent fisheries release program more responsive to the water conditions downstream of New York City Delaware Basin Reservoirs; and

WHEREAS, agreement on the permanent fisheries release program is not expected prior to April 30, 2002, the date at which the current program will automatically terminate; and

WHEREAS, the State of New York has proposed a revision and extension to Docket No. D-77-20 CP (Revision 4) for one calendar year ending April 30, 2003; and

WHEREAS, the requested revision and extension has been agreed to by all parties to the 1954 Supreme Court Decree; now therefore,

BE IT RESOLVED by the undersigned Commissioners and Parties to the Decree:

1. The Parties to the 1954 Supreme Court Decree agree that development of a viable permanent fisheries release program requires consideration of other related issues, including interbasin transfer policy, Good Faith operations, the DRBC Comprehensive Plan currently being developed, New York City participation, and procedures for computing the Excess Release Quantity.

2. Docket No. D-77-20 CP (Revision 4) is hereby extended for one year to April 30, 2003, with the following modifications.

   A. A "Habitat Bank" is established, which shall consist of 5,700 cfs-days that shall be contributed for one year only from the Excess Release Quantity (ERQ) as the ERQ is currently computed and such quantity of water as may be transferred from the Thermal Release (TRB) from time to time as may be necessary. The 5,700 cfs-days from the ERQ shall be credited on June 15, 2002, and any water remaining from that quantity shall expire on March 15, 2003. The 9,200 cfs-days TRB shall be credited on May 1, 2002 and expires on April 30, 2003.

   B. Upon entry into "Drought Watch," the remaining Thermal Release Bank shall be reduced by 15 percent.

   C. Upon entry into "Drought Warning," the remaining Thermal Release Bank shall be suspended until storage in the New York City Delaware River Basin Reservoirs is 25 billions gallons (bg) above the drought watch line for 15 consecutive days.

   D. The Habitat Bank may be used to meet the following targets in the West Branch Delaware River at Hale Eddy:

      During Normal Conditions - 225 cfs
      During Watch Conditions - 190 cfs
      During Warning Conditions - 150 cfs

   In addition, the Habitat Bank may be used for augmenting flows in the West Branch Delaware River at Hale Eddy, and, contingent on the prior approval of New York City, the East Branch Delaware River at Harvard and the Neversink River at Bridgeville, during normal, drought watch and drought warning conditions. Also, the Habitat Bank may be used as needed for augmenting flows during drought warning conditions to maintain summer baseline releases as stipulated in Docket No. D-77-20 CP (Revision 4).

   E. Upon entry into Drought Emergency, the Habitat Bank shall be suspended until storage in the New York City Delaware River Basin Reservoirs is 25 bg above the drought watch line for 15 consecutive days.

F. Conservation releases from Cannonsville Reservoir shall be:

During Normal Conditions - 45 cfs
During Drought Watch Conditions - 35 cfs
During Drought Warning Conditions - 23 cfs
During Drought Emergency Conditions - 8 - 23 cfs

However, all thermal release charges shall be calculated using the augmented releases rates stipulated in Docket No. D-77-20 CP (Revision 4).

G. Comparison of the difference between releases from the Habitat Bank and the conservation releases under D-77-20 CP (Revision 4) will be made and the difference debited or credited to the habitat bank. However, a negative balance in the Habitat Bank is not allowed.

H. All other conditions shall continue as specified in Docket No. D-77-20 CP (Revision 4).

I. This resolution takes effect immediately and will expire on April 30, 2003.

J. No additional water beyond that specified in this resolution will be made available.

/s/ Irene B. Brooks
Irene B. Brooks, Chairman pro tem

/s/ Pamela M. Bush
Pamela M. Bush, Esq., Commission Secretary

'PROVED: July 17, 2002

NO. 2003-4

DOCKET NO. D-77-20 CP (Revision 6)

DELAWARE RIVER BASIN COMMISSION

A RESOLUTION to extend Docket No. D-77-20 CP (Revision 5) (Amended) for one year to continue the experimental augmented conservation release program for the New York City Delaware Basin Reservoirs.

WHEREAS, Docket No. D-77-20 CP (Revision 5) (Amended) specified it would expire on April 30, 2003; and

WHEREAS, the Parties to the 1954 Supreme Court Decree are in the process of negotiating a permanent fisheries release program more responsive to the water conditions downstream of the New York City Delaware Basin Reservoirs; and

WHEREAS, the Parties to the 1954 Supreme Court Decree desire to develop a program for protecting tail water fisheries below the New York City Delaware Basin Reservoirs, based upon sustainable sources of water, including consideration of other down-basin needs; and

WHEREAS, the Delaware River Basin Commission (DRBC), through its Flow Management Technical Advisory Committee (FMTAC) and its Comprehensive Plan update process, is considering several approaches to assess overall needs in the tailwaters below the New York City Delaware Basin Reservoirs and in the main stem and bay; and

WHEREAS, the New York City Department of Environmental Protection (NYCDEP) and the New York State Department of Environmental Conservation (NYSDEC) have funded a modeling analysis of alternatives for a fisheries protection program for the reservoir tailwaters, and based on the results of this analysis, the NYSDEC will submit a formal proposal for an interim fisheries protection program for consideration by the parties to the 1954 Supreme Court Decree and the Commission; and

WHEREAS, the NYCDEP and NYSDEC have agreed to make their best efforts to complete updating the OASIS model, to complete analysis of alternatives for an interim fisheries protection program for the reservoir tailwaters, and to submit, by September 30, 2003, a formal proposal for consideration by the parties to the 1954 Supreme Court Decree and the Commission for interim fisheries protection while discussions continue toward development of a long-term flexible reservoir releases program; and

WHEREAS, agreement on the interim fisheries release program is not expected prior to April 30, 2003, the date upon which the current program will automatically terminate; and

WHEREAS, the State of New York has proposed a revision and extension to Docket No. D -77-20 CP (Revision 5) (Amended) for one calendar year ending April 30, 2004; and

WHEREAS, the requested revision and extension has been agreed to by all parties to the 1954 Supreme Court Decree; now therefore,

BE IT RESOLVED by the undersigned Commissioners and Parties to the Decree:

1. The Parties to the 1954 Supreme Court Decree agree that development of a viable permanent fisheries release program requires consideration of other related issues, including interbasin transfer policy, Good Faith operations, the DRBC Comprehensive Plan currently being developed, New York City participation, and procedures for computing the Excess Release Quantity.

2. The Parties to the 1954 Supreme Court decree commit to continuing discussions with the aid of one or more approaches being considered by the FMTAC and in the Comprehensive Plan update, with the goal of developing a long-term, flexible program to manage releases from the NYC Delaware Basin reservoirs.

3. Docket No. D-77-20 CP (Revision 5) (Amended) is hereby extended for one year to April 30, 2004, with the following modifications.

A. A "Habitat Bank" is established, which shall consist of 4,567 cfs-days that shall be contributed for one year only from the Excess Release Quantity (ERQ) as the ERQ is currently computed and such quantity of water as may be transferred from the Thermal Release Bank (TRB) from time to time as may be necessary. The 4,567 cfs-days from the ERQ shall be credited on June 15, 2003, and any water remaining from that quantity shall expire on March 15, 2004. The 9,200 cfs-days TRB shall be credited on May 1, 2003, and shall expire on April 30, 2004. Waters from the ERQ not contributed to the Habitat Bank shall be utilized to provide a proportionally-reduced increase in the Montague flow objective according to the current procedures, or may be banked in accordance with the procedures outlined in the Lower Basin Drought Management Plan.

B. Upon entry into "Drought Watch," the remaining TRB shall be reduced by 15 percent.

C. Upon entry into "Drought Warning," the remaining TRB shall be suspended until storage in the New York City Delaware River Basin Reservoirs is 25 billions gallons (bg) above the Drought Watch line for 15 consecutive days.

D. The Habitat Bank may be used to meet the following targets in the West Branch Delaware River at Hale Eddy:

During Normal Conditions - 225 cfs
During Watch Conditions - 190 cfs
During Warning Conditions - 150 cfs

The Habitat Bank also may be used for augmenting flows in the West Branch, Delaware River at Hale Eddy, and contingent on the prior approval of New York City, the East Branch Delaware River at Harvard and the Neversink River at Bridgeville, during normal, Drought Watch and Drought Warning conditions. In addition, the Habitat Bank may be used as needed for augmenting flows during Drought Warning conditions to maintain summer baseline releases as stipulated in Docket No. D-77-20 CP (Revision 4).

E. Upon entry into Drought Emergency, the Habitat Bank shall be suspended until storage in the New York City Delaware River Basin Reservoirs is 25 bg above the Drought Watch line for 15 consecutive days.

F. Conservation releases from Cannonsville Reservoir shall be:

During Normal Conditions - 45 cfs
During Drought Watch Conditions - 35 cfs
During Drought Warning Conditions - 23 cfs
During Drought Emergency Conditions - 8 - 23 cfs

However, all thermal release charges shall be calculated using the augmented release rates stipulated in Docket No. D-77-20 CP (Revision 4).

G. Comparison of the difference between releases from the Habitat Bank and the conservation releases under D-77-20 CP (Revision 4) shall be made and the difference debited or credited to the habitat bank. However, a negative balance in the Habitat Bank is not allowed.

H. All other conditions shall continue as specified in Docket No. D-77-20 CP (Revision 4).

I. No additional water beyond that specified in this resolution will be made available.

4. These specific conservation releases are not available when coming out of Drought Emergency until storage is 25 bg above the Drought Watch line for 15 consecutive days.

5. By April 30, 2004, NYSDEC shall submit to the Commission and to the Parties to the 1954 Supreme Court decree a report, including an executive summary, describing experience with implementation of this resolution and the progress of any negotiations leading toward further amendments to this resolution. Discussion of such reports shall be included as an agenda item on the annual meeting of the Delaware River Master's Advisory Committee.

NO. 2004-3 *

DOCKET NO. D-77-20 CP (Revision 7)

DELAWARE RIVER BASIN COMMISSION

A RESOLUTION, superseding and incorporating as necessary certain provisions of Resolutions D-77-20 CP (Revision 2) through D-77-20 CP (Revision 6), to establish an experimental augmented conservation release program for the New York City Delaware Basin Reservoirs for the period beginning May 1, 2004 and ending May 31, 2007, and to engage in discussions to develop a long-term, flexible program to manage releases from the reservoirs.

WHEREAS, Docket No. D-77-20 CP (Revision 6) expires on April 30, 2004; and

WHEREAS, it is the objective of the Parties to the 1954 Supreme Court Decree, hereafter the Decree Parties, to develop a program for protecting tail water fisheries below New York City's Delaware Basin Reservoirs, hereafter City Delaware Reservoirs, based upon sustainable sources of water, while considering overall needs in the tailwaters below the City Delaware Reservoirs and in the main stem and bay; and

WHEREAS, the Delaware River Basin Commission (DRBC), through its Flow Management Technical Advisory Committee (FMTAC) and its Comprehensive Plan update process, is considering several approaches to assess overall needs in the tailwaters below the City Delaware Reservoirs and in the main stem and bay; and

WHEREAS, Docket No. D-77-20 CP (Revision 6) provided that the New York City Department of Environmental Protection (NYCDEP) and the New York State Department of Environmental Conservation (NYSDEC) fund an update of the OASIS model and analysis of alternatives for an interim fisheries protection program for the City Delaware Reservoir tailwaters and, based on the results of this analysis, submit by September 30, 2003 a formal proposal for consideration by the Decree Parties and the DRBC for interim fisheries protection while discussions continue toward development of a long-term flexible reservoir releases program; and

WHEREAS, the State of New York has proposed an interim reservoir releases program to maintain target flows in the tailwaters below the City Delaware Reservoirs for the period beginning May 1, 2004 and ending May 31, 2007; and

WHEREAS, the proposed interim reservoir releases program will allow for more comprehensive and flexible management of releases in response to temperature and flow conditions in the New York City Delaware Basin reservoir tailwaters and upper main stem Delaware; and

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* By Resolution No. 2007-7 approved on May 10, 2007, the Commission extended through September 30, 2007 the reservoir releases program established by Resolution No. 2004-3.

WHEREAS, populations of dwarf wedgemussels, a federally- and state-listed endangered species, are known to exist in the Neversink River and mainstem Delaware River; and

WHEREAS, Resolution No. 2002-33 approved a "Drought Operations Plan for Lake Wallenpaupack", implementation of which is contingent upon the Decree Parties agreeing upon a reservoir releases program for the City Delaware Reservoirs that ameliorates any adverse impact of releases from Lake Wallenpaupack under the provisions of Resolution No. 2002-33; and

WHEREAS, NYSDEC, in collaboration with the Subcommittee on Ecological Flows (SEF) and the FMTAC, has developed a "Monitoring Plan for the Delaware River Tailwaters, 2004-2006" (Monitoring Plan); and

WHEREAS, the Monitoring Plan and the proposal described herein have been agreed to by all Decree Parties; now therefore,

BE IT RESOLVED by the undersigned Commissioners and Decree Parties:

1. The Decree Parties agree that development and implementation of a viable long-term program to address fisheries and other needs in the tailwaters below the City Delaware Reservoirs and in the main stem and bay requires consideration of other related issues, including interbasin transfer policy, Good Faith operations, New York City water supply needs, the DRBC Comprehensive Plan, the Basinwide Plan currently being developed, Montague flow targets, the Excess Release Quantity, and equitable apportionment of the waters of the Delaware Basin in accordance with the provisions of the 1954 Decree and the provisions of Docket D-77-20CP as revised which are not being superseded hereby.

2. The Decree Parties commit to continuing discussions with the aid of the FMTAC guided by the Comprehensive Plan and the Basinwide Plan currently under development, with the objective of developing and implementing by May 31, 2007 a long-term, flexible program to manage releases from the City Delaware Reservoirs to better address fisheries in the tailwaters below the City Delaware Reservoirs. The long-term program must take into account needs in the main stem and the bay as well as the related issues recited in Paragraph 1 above.

3. During the effective period of the interim proposal, the following drought stage definitions and procedures will be in effect:

   A. <u>Drought Watch.</u>

   The seasonally segmented line (shown as dashes) splitting the current "Drought Warning" in Figure 1 of DRBC Resolution No. 83-13 and DRBC Docket No. D-77-20 CP (Revised) is temporarily raised by four (4) billion gallons during the entire year. In addition, the upper half of the drought warning, previously referred to as DWI, is temporarily renamed Drought Watch. Operations during the renamed Drought Watch shall continue to limit the diversion by New York City to 680 million gallons per day (mgd) and reduce the Montague and Trenton flow targets to 1,655 cubic feet per second (cfs) and 2,700 cfs, respectively. The

New Jersey diversion will remain at 100 mgd.

B. Drought Warning.

The lower half of the drought warning (DW2), based upon the rule curves included in DRBC Resolution No. 83-13 and as temporarily modified by "A" above, is designated Drought Warning, with diversions and the flow targets at Montague and Trenton conforming to DRBC Resolution No. 83-13 for the former DW2.

C. Drought Emergency.

The Drought Emergency provision shall remain at the levels designated in DRBC Resolution No. 83-13.

D. Balancing Adjustment.

In order to conserve water, the Delaware River Master is requested to utilize a balancing adjustment when calculating the releases to be directed to meet the Montague target.

4. There is hereby established, for thermal and habitat protection in the tailwaters below the City Delaware Reservoirs, for the period beginning May 1, 2004 and ending May 31, 2007, a Habitat Protection Bank (HPB), with the following provisions:

A. A "Habitat Protection Bank (HPB)" of 20,000 cubic feet per second days (cfs-days) is established, which shall consist of: an Excess Release Quantity Bank (ERQB) of 5,700 cfs-days, provided from the Excess Release Quantity (ERQ); a Thermal Release Bank (TRB) of 9200 cfs-days; and a Supplemental Release Bank (SRB) of 5,100 cfs-days. Water from the ERQ shall be credited on June 15, and any water remaining from that quantity shall expire on March 15 of the following year. The 9,200 cfs-days TRB and 5,100 cfs-days SRB shall be credited on May 1, and any water remaining in these banks shall expire on April 30 of the following year. In any year during which the Drought Operations Plan for Lake Wallenpaupack is not in effect, the HPB shall be limited to 16,000 cfs-days, consisting of: an ERQB of 3,420 cfs-days from the ERQ; a TRB of 9,200 cfs-days; and an SRB of 3,380 cfs-days. Waters from the ERQ not contributed to the HPB shall be utilized to provide a proportionally-reduced increase in the Montague flow objective according to the current procedures, or may be banked in accordance with the procedures outlined in the Lower Basin Drought Management Plan. In addition, an Amelioration Bank (AB) of 3,000 cfs-days may be available subject to the provisions of Paragraph 6.

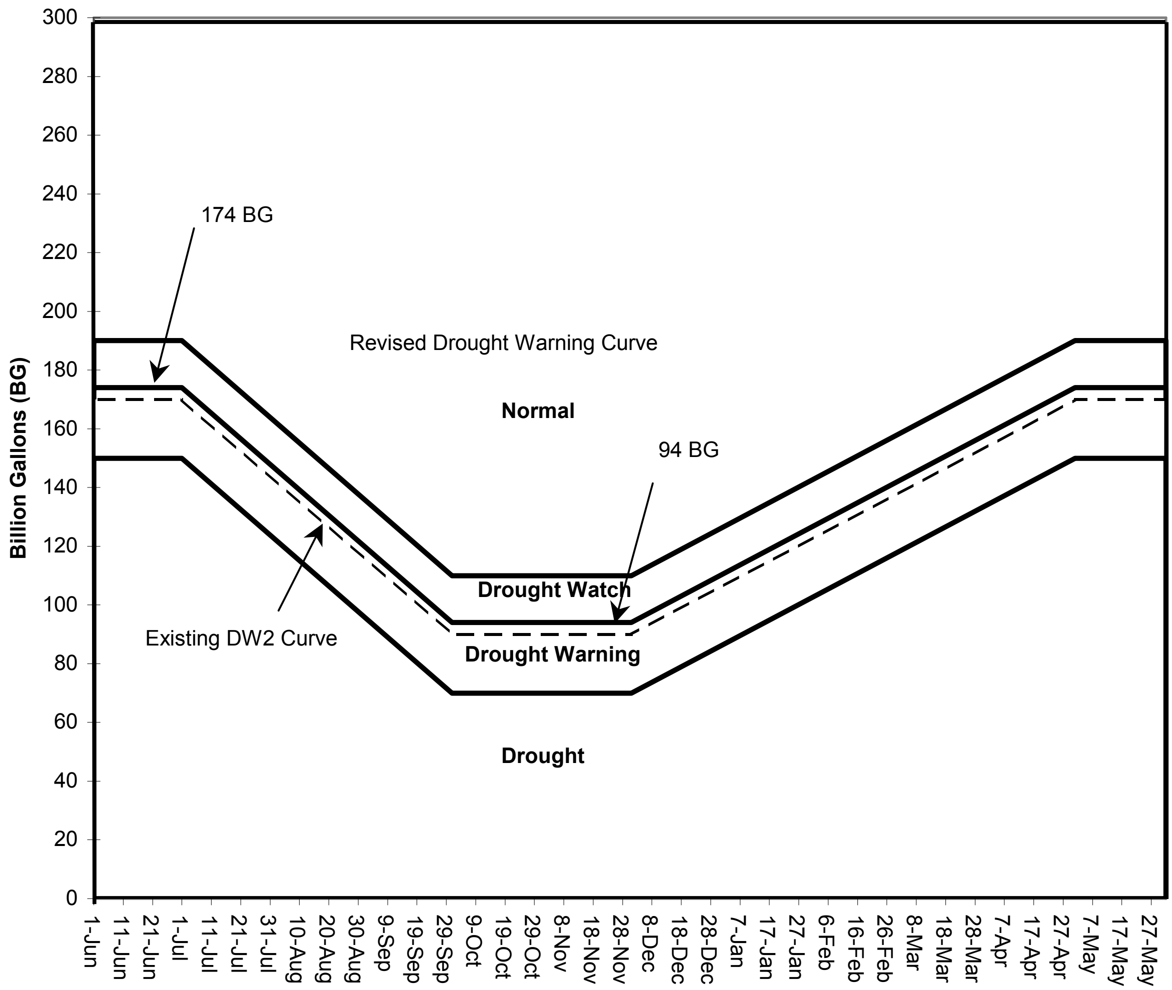
B. The TRB shall be used to direct releases during May 1 through October 31 so as to prevent to the maximum extent possible any instantaneous water temperature higher than 75° F or any daily average temperature higher than 72° F in the designated downstream areas as determined from measurements at the Hale Eddy, Harvard, Bridgeville, Hancock and Hankins gaging stations. Designated downstream areas shall mean the following waters:

- The West Branch Delaware River between Cannonsville Reservoir and Hancock, NY
- The East Branch Delaware River between Pepacton Reservoir and the confluence of the East Branch Delaware River and the Beaver Kill
- The Delaware River between Hancock, NY and Hankins, NY
- The Neversink River between Neversink Reservoir and Bridgeville, NY

Any quantity of water remaining in the TRB after October 31 may subsequently be used for habitat protection.

C. Upon entry into Drought Watch (Figure 1), the remaining quantity of water in the TRB and SRB shall each be reduced by 15 percent. In addition, 2000 cfs-days of water from the Amelioration Bank (AB) would be made available subject to the provisions of Paragraph 6.

Figure 1.
New York City Delaware Basin Reservoir Experimental Rule Curve



D. Upon entry into Drought Warning (Figure 1), the remaining quantity of water in the TRB and SRB shall each be reduced by 15 percent. In addition, any water remaining in the 2000 cfs-day AB would be made available subject to the provisions of Paragraph 6.

E. Upon entry into Drought (Figure 1), habitat and thermal protection may be provided, except as noted in Paragraph M, subject to the availability of the ERQB and at the discretion of the down-basin parties to the 1954 U. S. Supreme Court Decree. Any releases from the water remaining in the TRB and SRB shall be suspended until storage in the City Delaware Reservoirs is 25 billion gallons (BG) above the Drought Watch line for 15 consecutive days. The most severe set of conservation releases and tailwater flow targets realized as described in Paragraph F through M will remain in effect until storage in the City Delaware Reservoirs is 25 BG above the Drought

Warning line for 15 consecutive days. . In addition, any water remaining in the total AB would be made available subject to the provisions of Paragraph 6.

F. At the direction of the NYSDEC, the HPB may be used to meet the flow targets in Table 1.

Table 1
Habitat Protection Bank Flow Targets

	Flow Target (cfs)			
Target Location	*Normal*	*Drought Watch*	*Drought Warning*	*Drought**
West Branch Delaware R At Hale Eddy	225	190	160	145
East Branch Delaware R At Harvard	175	150	120	115
Neversink River At Bridgeville	115	100	80	75

** Subject to the availability of the ERQB and at the discretion of the down-basin parties to the 1954 U. S. Supreme Court Decree, or availability of the Amelioration Bank (AB).*

G. Conservation releases from the City Delaware Reservoirs shall be as specified in Table 2 with additional releases directed by the NYSDEC to maintain tributary target flows as specified in Paragraph F.

Table 2
Conservation Releases

	Conservation Release (cfs)			
Reservoir	*Normal*	*Drought Watch*	*Drought Warning*	*Drought*
Cannonsville (9/1-5/31)	45	38	32	23
Cannonsville (6/1-8/31)	60	51	43	23
Pepacton	35	30	25	19
Neversink	25	21	18	15

H. The difference between releases resulting from reservoir release operations specified in Paragraphs F and G, and the reference conservation releases specified in Table 3, shall be debited or credited to the HPB. However, a negative balance in the HPB is not allowed.

Table 3
Reference Conservation Releases

Reservoir and Operation Dates	*Normal*	*Drought Watch*[(1)]	*Drought Warning*[(2)]	*Drought*[(2)]
	- - - - - - - - - - - - Release Rate (cfs)	*- - - - - - - - - - - -*		
Cannonsville				
1/1 – 4/15	45	38	8	8
4/16 – 5/31	45	38	23	23
6/1 – 9/15	160	136	23	23
9/16 – 11/30	45	38	23	23
12/1 – 12/31	45	38	8	8
Pepacton				
1/1 – 4/7	45	38	6	6
4/8 – 4/30	45	38	19	19
5/1 – 5/31	70	60	19	19
6/1 – 8/31	95	81	19	19
9/1 – 9/30	70	60	19	19
10/1 – 10/31	45	38	19	19
11/1 – 12/31	45	38	6	6
Neversink				
1/1 – 4/7	25	21	5	5
4/8 – 4/30	25	21	15	15
5/1 – 9/30	53	45	15	15
10/1 – 10/31	25	21	15	15
11/1 – 12/31	25	21	5	5

(1) 85 percent of the normal conservation release rates.
(2) Basic conservation release rates as specified in Table 4.

I. In the event that banks are exhausted, conservation releases continue as specified in Table 3.

J. No additional water beyond that specified in this resolution will be made available under any circumstances.

K. When the combined ERQB and SRB are exhausted, flow targets shall be suspended and only conservation releases as specified in Table 3 can be made, except after October 31 as provided in Paragraph 4 or at those times when the AB is available subject to the provisions of Paragraph 6.

L. In order to assure the delivery of high quality drinking water to New York City and neighboring outside communities, it may be necessary from time to time to decrease or cease the diversion of water from Cannonsville Reservoir, and increase the diversion of higher quality water from Neversink Reservoir. At such times, in order to conserve storage of Neversink Reservoir water, flow targeting at Bridgeville, N.Y. will be suspended and releases will be reduced to the augmented conservation release rates specified in Table 3; these program modifications will remain in effect until such time as Cannonsville Reservoir water quality improves to a level satisfying the criteria below. Prior to initiating such an action, the City of New York will consult with the Decree Parties. The suspension and re-initiation of flow targeting at Bridgeville will be based upon either of the following water quality criteria:

(1) The diversion from Cannonsville Reservoir, based upon a 5-day running average, exceeds any of the following trigger levels for five key water quality parameters:

- Total Phosphorus = 20 μg/L
- Fecal coliform = 20 CFU/100 mL
- Total Coliform = 1000 CFU/100 mL
- Turbidity = 5 NTU
- Total Phytoplankton = 1000 SAU/mL; or

(2) The water quality in the diversion from Cannonsville Reservoir, based upon a 5-day running average, exceeds 50% of any parameter indicated in Subparagraph (1) above and the difference in that value of the parameter is greater than 200% of the value of the same parameter in the diversion from Neversink Reservoir, based upon 5-day running averages.

(For example, if the turbidity exceeds 4 NTU in the diversion from Cannonsville Reservoir and is less than 2 NTU in the diversion from Neversink Reservoir, NYCDEP may temporarily suspend the flow target at Bridgeville and return to conservation releases as described in Table 3)

M. Should combined storage in Neversink, Pepacton, and Cannonsville Reservoirs drop below 25% usable capacity (i.e., less than 67.7 BG), water would be available for thermal mitigation by NYSDEC, from the ERQB, subject to the discretion of the downbasin parties to the 1954 U.S. Supreme Court Decree, and flow targeting at Bridgeville, Harvard, and Hale Eddy will be suspended, until storage recovers to 5 billion gallons above the Drought Watch (Figure 1) line for one day. Conservation releases will be made as specified in Table 4. Under this condition, there will be no debiting or crediting of the HPB, unless the ERQB has been made available, in which case there will be debiting of the ERQB.

Table 4
Basic Conservation Releases

Reservoir and Operation Dates	*Release Rate (cfs)*
Cannonsville	
4/1 – 4/15	8
4/16 – 11/30	23
12/1 – 3/31	8
Pepacton	
4/1 – 4/7	6
4/8 – 10/31	19
11/1 – 3/31	6
Neversink	
4/1 – 4/7	5
4/8 – 10/31	15
11/1 – 3/31	5

5. NYSDEC shall conduct an evaluation in accordance with the Monitoring Plan. The evaluation shall assess the response of tailwater biota, particularly brown and rainbow trout populations, to the experimental release and target flow protocols established herein. The evaluation plan shall include the following components: evaluation need(s), purpose and scope, objectives, approach and methods, evaluation benefits, content of planned reports, evaluation schedule, personnel needs, budget, and source of funds. Where appropriate, results of previous investigations conducted as part of the historical experimental release program shall be included in the evaluation plan.

   NYSDEC shall, on February 28, 2005 and February 28, 2006, submit to the DRBC and to the Decree Parties annual interim progress reports on the study. The initial report to be submitted on February 28, 2005 shall incorporate summary data and conclusions obtained since the experimental release program was initiated in 1977. Discussion of such reports shall be included as an agenda item at annual meetings of the Delaware River Master Advisory Committee.

   By December 31, 2006, NYSDEC shall submit a draft scientific report, which shall include an abstract or executive summary, statements of purpose, scope and objectives, procedures, results, conclusions, recommendations for additional work if warranted, and supporting literature, and shall describe effects on the fishery and other aquatic resources resulting from implementation of this resolution.

   By May 31, 2007, NYSDEC shall submit a final scientific report.

6. In any year during which the Drought Operations Plan for Lake Wallenpaupack is in effect, if on May 1 the basin is not in Normal (see Figure 1), or if after May 1 the basin enters

Drought Watch, an Amelioration Bank (AB) of 3,000 cfs-days will be created. During Drought Watch and Drought Warning (see Figure 1), a total of releases not to exceed 2,000 cfs-days may be made from the AB to meet the target flows according to Table 1. During Drought (see Figure 1), the remainder of the 3,000 cfs-day AB may be used to maintain conservation releases in accordance with Table 2 and for thermal protection in accordance with Paragraph 4.B. Any remaining AB will expire on April 30.

7. In any year during which the Drought Operations Plan for Lake Wallenpaupack is not in effect, releases for flow targeting will only be made from Cannonsville Reservoir for targets at Hale Eddy, to conserve the available bank. No releases will be made for flow targeting from Neversink or Pepacton Reservoirs. Releases from Neversink and Pepacton Reservoirs will be in accordance with Table 3.

8. The Commission and the Decree Parties will review and evaluate available data during the implementation of this program and will consider any modifications that may be necessary to avoid adverse effect to dwarf wedgemussels.

9. This resolution shall take effect upon consent by the Decree Parties and shall expire on May 31, 2007, or earlier either upon a determination by the down-basin parties to the 1954 Supreme Court Decree that the requirements of Paragraph 5 have not been met or when an alternative long-term tailwaters fisheries program, unanimously approved by the Decree Parties, is implemented.

10. Approval of and unanimous consent to this Resolution shall be deemed as approval of and consent to the reservoir releases program for the New York City Delaware River Basin reservoirs as specified in Article 3 of Resolution No. 2002-33.

11. For the effective period, this Resolution shall supersede Resolutions D-77-20 CP (Revision 2) through D-77-20 CP (Revision 6).

/s/ Fred Nuffer
Fred Nuffer, Acting Chairman *pro tem*

/s/ Pamela M. Bush
Pamela M. Bush, Esquire, Commission Secretary

ADOPTED: April 21, 2004

Appendix D Flexible Flow Management Plan

This appendix presents Flexible Management Plan for current reservoir operations

D.1. Flexible Flow Management Program

Minimum releases from the New York City (NYC) Delaware River Basin Reservoirs under drought conditions are made in accordance with the Table D.1-1.

NYC is using Operations Support Tool (OST) to determine Forecast-based Available Water (FAW), which is used to enhance stream releases. The appropriate FAW or the base releases are shown in Table D.1-2. If the OST assessment indicates that there is no available water in the reservoirs, the releases are made based on currently sustainable base releases shown in Table D.1-2. Table D.1-3 through Table D.1. - 8 illustrate the releases schedules under normal conditions for pre-determined amounts of FAW (DRBC, 2014).

Table D.1-1 Schedule of Releases (cfs) during Drought Operations

Storage Zone	Winter		Spring		Summer			Fall		
Cannonsville	Dec 1 –Mach 31	Apr 1 –Apr 30	May 1-May 20	May 21-May 31	Jun 1–Jun15	Jun 16-Jun30	Jul 1-Aug 31	Sep 1-Sep 15	Sep 16-Sep 30	Oct 1-Nov 30
L3	55	55	85	85	135	135	135	85	85	55
L4	50	50	60	60	100	100	100	50	50	50
L5	40	40	40	40	90	90	90	40	40	40
Pepacton										
L3	45	45	60	60	75	75	75	45	45	45
L4	40	40	50	50	65	65	65	40	40	40
L5	35	35	35	35	60	60	60	35	35	35
Neversink										
L3	30	30	40	40	55	55	55	30	30	30
L4	25	25	30	30	45	45	45	25	25	25
L5	20	20	20	20	40	40	40	20	20	20

Table D.1-2. Schedule of releases (cfs) during normal conditions base releases with no forecast-based available water (FAW)

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1-May 20	May 21- May 31	Jun 1– Jun15	Jun 16- Jun30	Jul 1- Aug 31	Sep 1-Sep 15	Sep 16- Sep 30	Oct 1- Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	400	400	*	*	*	*	400	400	400	400
L1-c	110	110	200	250	275	275	275	275	175	110
L2-a	75	75	150	200	225	225	225	225	150	75
L2-b	60	60	135	175	190	190	190	190	135	60
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	300	300	*	*	*	*	300	300	300	300
L1-c	85	85	110	130	150	150	150	150	100	85
L2	50	50	75	90	100	100	100	100	60	50
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	65	65	85	100	110	110	110	100	75	65
L2	35	35	55	65	75	75	75	65	50	35

*Indicates storage zone not present at this time period; release is entry in the cell below.

Table D.1 -3. Schedule of releases (cfs) during normal conditions base releases with 10 mgd forecast-based available water (FAW)

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1-May 20	May 21-May 31	Jun 1–Jun15	Jun 16-Jun30	Jul 1-Aug 31	Sep 1-Sep 15	Sep 16-Sep 30	Oct 1-Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	400	400	*	*	*	*	400	400	400	400
L1-c	125	125	225	300	300	300	300	300	200	125
L2-a	85	85	160	235	245	245	245	235	160	85
L2-b	70	70	140	200	210	210	210	200	140	70
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	300	300	*	*	*	*	300	300	300	300
L1-c	85	85	110	130	150	150	150	150	110	85
L2	55	55	75	100	110	110	110	100	75	55
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	70	70	85	100	110	110	110	100	85	70
L2	40	40	60	75	80	80	80	75	60	40

*Indicates storage zone not present at this time period; release is entry in the cell below.

Table D.1-4. Schedule of releases (cfs) during normal conditions base releases with 20 mgd forecast-based available water (FAW).

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1-May 20	May 21-May 31	Jun 1–Jun15	Jun 16-Jun30	Jul 1-Aug 31	Sep 1-Sep 15	Sep 16-Sep 30	Oct 1-Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	500	500	*	*	*	*	500	500	500	500
L1-c	150	200	250	300	325	325	325	325	225	150
L2-a	90	140	175	260	275	275	275	260	170	90
L2-b	80	90	150	220	240	240	240	220	145	80
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	300	300	*	*	*	*	300	300	300	300
L1-c	100	100	110	130	150	150	150	150	125	100
L2	60	60	85	110	125	125	125	110	85	60
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	70	70	85	100	110	110	110	100	85	70
L2	45	45	65	80	90	90	90	80	65	45

*Indicates storage zone not present at this time period; release is entry in the cell below.

Table D.1-5. Schedule of releases (cfs) during normal conditions base releases with 35 mgd forecast-based available water (FAW)

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1-May 20	May 21-May 31	Jun 1–Jun15	Jun 16-Jun30	Jul 1-Aug 31	Sep 1-Sep 15	Sep 16-Sep 30	Oct 1-Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	600	600	*	*	*	*	600	600	600	600
L1-c	175	250	300	375	400	400	400	375	275	175
L2-a	110	175	225	300	325	325	325	300	210	110
L2-b	90	115	175	250	275	275	275	250	150	90
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	300	300	*	*	*	*	300	300	300	300
L1-c	100	100	110	130	150	150	150	150	125	100
L2	70	70	90	125	140	140	140	125	90	70
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	75	75	100	100	125	125	100	100	85	75
L2	50	50	70	90	100	100	90	75	65	50

*Indicates storage zone not present at this time period; release is entry in the cell below.

Table D.1-6. Schedule of releases (cfs) during normal conditions base releases with 50 mgd forecast-based available water (FAW)

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville e	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1-May 20	May 21-May 31	Jun 1–Jun15	Jun 16-Jun30	Jul 1-Aug 31	Sep 1-Sep 15	Sep 16-Sep 30	Oct 1-Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	700	700	*	*	*	*	700	700	700	700
L1-c	200	325	400	400	500	500	500	400	325	200
L2-a	125	200	250	325	400	400	400	325	250	125
L2-b	100	150	200	275	300	300	300	275	150	100
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	500	500	*	*	*	*	500	500	500	500
L1-c	150	150	150	150	150	150	150	150	150	150
L2	80	80	100	125	140	140	140	140	100	80
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	75	75	100	100	140	140	140	100	100	75
L2	50	50	75	90	100	100	100	90	75	50

*Indicates storage zone not present at this time period; release is entry in the cell below.

Table D.1-7. Schedule of releases (cfs) during normal conditions base releases with 75 mgd forecast-based available water (FAW)

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1- May 20	May 21- May 31	Jun 1– Jun15	Jun 16- Jun30	Jul 1- Aug 31	Sep 1- Sep 15	Sep 16- Sep 30	Oct 1- Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	700	700	*	*	*	*	700	700	700	700
L1-c	225	475	475	525	600	500	600	475	375	225
L2-a	150	400	400	400/450+	500/525+	500/525+	500/525+	400	300	150
L2-b	100	150	200	275	300	300	300	275	200	100
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	500	500	*	*	*	*	500	500	500	500
L1-c	150	150	150	150	150	150	150	150	150	150
L2	100	100	100	125	140	140	140	140	100	100
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	75	75	100	100	140	140	140	100	100	75
L2	55	55	90	90	110	110	110	90	90	55

*Indicates storage zone not present at this time period; release is entry in the cell below.

+ Second entry after slash indicates reduction in release rate for New Jersey Diversion Offset Bank

Table D.1-8. Schedule of releases (cfs) during normal conditions base releases with 100 mgd forecast-based available water (FAW)

Storage Zone	Winter		Spring		Summer			Fall		
Cannosville	Dec 1 – Mach 31	Apr 1 –Apr 30	May 1- May 20	May 21- May 31	Jun 1– Jun15	Jun 16- Jun30	Jul 1- Aug 31	Sep 1- Sep 15	Sep 16- Sep 30	Oct 1- Nov 30
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	700	700	*	*	*	*	700	700	700	700
L1-c	225	475	475	525	600	600	600	475	375	225
L2-a	150	400	400	400/450+	500/525+	500/525+	500/525+	400	300	150
L2-b	150	400	400	400/450+	500/525+	500/525+	500/525+	400	300	150
Pepacton										
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	500	500	*	*	*	*	500	500	500	500
L1-c	150	150	150	150	150	150	150	150	150	150
L2	100	100	100	140	140	140	140	140	100	100
Neversink										
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	125	110	*	*	*	*	150	150	150	125
L1-c	75	75	100	100	140	140	140	100	100	75
L2	55	55	90	90	110	110	110	90	90	55

*Indicates storage zone not present at this time period; release is entry in the cell below.

+ Second entry after slash indicates reduction in release rate for New Jersey Diversion Offset Bank

D.2. Section References

Delaware River Basin Comission (DRBC). 2014. The 2014 version of Flexible Flow Management Plan is posted on the ODRM website.